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Honourable Richard Hurlburt
Minister

P. C. Underwood
Deputy Minister

Halifax, Nova Scotia
2005

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Cover photo

Outcrop of hydrothermally altered gabbro from the Culloden Road Pluton near Lorne, Pictou County. Note the northeast-trending sheeted quartz-carbonate veins filling extensional fractures (compass pointing north). Plutons of mafic composition, many with attendant hydrothermal alteration, are common along the northern scarp of the St. Marys Graben and are emplaced along splay faults of the Cobequid-Chedabucto Fault Zone. Photo by G. A. O'Reilly; see p. 81.

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Mineral Inventory Studies in Cape Breton Island

G. J. DeMont

Revision of the data for industrial mineral occurrences in the Mineral Occurrences Database was the focus of the Cape Breton Island component of the Mineral Inventory Project in 2004. Metallic mineral occurrence records for most of Cape Breton Island were completed prior to 2004, but recently released assessment reports are reviewed on a regular basis, and any new mineral occurrence data found in them are compiled and added to the database records.

In the summer and fall of 2004, site visits were made to several mineral occurrences and more detailed resource evaluation studies were undertaken on the Eden clay deposit, and the Ironville and Cape Dauphin carbonate deposits (Fig. 1). The clay deposit study was funded by DNR, Strait Highlands Regional Development Agency, Nova Scotia Department of Economic Development, Enterprise Cape Breton and the Tar Ponds Agency. As part of the Eden Project, a technical partner, Dr. Craig Lake, was invited to join the project team. Dr. Lake is located at the Dalhousie University Engineering Department, where he operates an engineering lab that specializes in testing construction material used in landfill or hazardous waste disposal sites.

New data collected in 2004 will be compiled and added to the Mineral Occurrences Database. In addition, 1:20 000 scale carbonate resource maps will be produced in ArcView® for the Ironville and Cape Dauphin deposits. The updated database and resource maps will be released in 2005. Summaries of two of the resource evaluation studies are provided below.

Ironville Carbonate Deposit

Two areas of Precambrian metasedimentary and metacarbonate rocks are found in the Boisdale Hills. They are separated by a northeast-trending fault and a linear band of Cambrian sedimentary and volcanic rocks. Although the Precambrian rocks found north of the fault are not well mapped, there are enough data to suggest a pronounced change in metamorphic grade across the fault, with amphibolite facies to the south, and greenschist facies to the north.

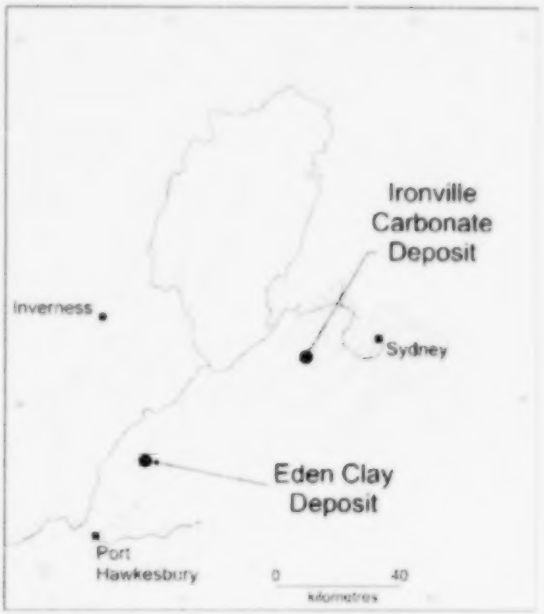

Figure 1. Locations of the Eden clay deposit (NTS 11F/14), Inverness County, and the Ironville carbonate deposit (NTS 11K/01), Cape Breton County.

South of the fault, the Precambrian rocks occur in a narrow, northeast-trending band that roughly parallels the south side of the Boisdale Hills, between Eskasoni and Scotch Lake. Carbonate rocks are common in this block. Large tonnages of dolomite and magnesian-limestone were quarried at Frenchvale and Scotch Lake for use as a fluxing agent in the Sydney Steel Plant. These rocks were historically included as part of the George River Group, but in more recent studies they were redefined as the Bras d'Or Gneiss. Calc-silicate minerals are common in the impure carbonate beds a result of amphibolite facies metamorphism.

Four discontinuous blocks of Precambrian strata found north of the fault are included as part of the George River Group. They are largely unmapped, with the exception of local areas, such as Ironville, where they were the subject of detailed mineral exploration surveys. Metamorphic grade is generally greenschist facies, but higher metamorphic grades are found locally. The extent

DeMont, G. J. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 1-2.

of carbonate rocks within the blocks is not well defined. Assessment reports documenting the work undertaken on the Ironville iron deposits reported the presence of limestone in the workings, but no effort was made to define its extent or grade.

A Nova Scotia Department of Mines report by G. V. Douglas (1944) documents a limestone deposit at Ironville. Douglas focused his studies on the north end of the deposit where a wide section is exposed in the railway cut. The analytical data provided in his report suggest the limestone is too impure for most applications, but samples collected in 2004, in the southern half of the deposit, indicate better quality stone is available at this site. None of the analyses showed the purity required for lime production, but they were certainly within the range required for the manufacture of Portland cement. Further mapping and drilling are required to define tonnage reserve estimates and grades. The proximity of a rail line to this site should make this deposit of interest to anyone looking for carbonate resources to feed a cement plant operation.

Eden Clay Deposit

In 2003-04, the Cape Breton and Central Nova Scotia Railway applied for permission to abandon the Port Hawkesbury to Sydney section of the rail line. The provincial government realized that new cargoes must be identified to save this critical transportation link so DNR staff commenced an assessment of the industrial mineral deposits found along the rail line corridor. Early in this assessment process, the author identified the Sydney Tar Ponds Cleanup Project as a potential market for large volumes of sand and clay.

The River Denys and Eden areas, and in particular the latter, were selected as sites with the potential to host large clay and sand deposits close to the rail line corridor. A brick factory operating at Eden Siding in the early 1900s supplied bricks for construction of some of the numerous buildings found at the Sydney Steel Plant. It is fitting, therefore, that Eden is now being considered as a source area for the clay required for capping the Sydney Tar Ponds and former Steel Plant sites.

The clay quarried at Eden Siding forms part of a large glaciolacustrine deposit mapped by Stea and Feetham (2003). Pit development was restricted to one small corner of the deposit, leaving an extensive area for future exploration and development.

In the summer of 2004, DNR staff undertook a reconnaissance hand auger survey of the Eden area to evaluate its potential as a source area for the sand and clay. Results of this survey were positive so meetings were arranged with the Sydney Tar Ponds Agency, Albert Leblanc of the Nova Scotia Office of Economic Development, and staff of the Nova Scotia Department of Environment and Labour. This led to a more detailed assessment of the deposit by the partner agencies. A grid soil auger survey was completed to locate areas with the best potential to contain a deposit of near-surface clay. This was followed up by a two day excavator trenching survey.

Greater than 5 m of clay were found in the trenches excavated along the edge of the rail line, but clay thicknesses of 2.5 to 3.5 m were more common to the west. The clay is massive, with few drop stones and little indication of bedding. Present day topography is used to define the approximate edges of this former lake basin. The clay was found to occur in topographically low areas, where the ground surface was flat over a large area, and commonly wet. Stony till, marking the position of the lake shoreline, becomes prevalent at surface or beneath a shallow cover of clay around the edges of this flat surface, where topographic elevation changes by +1-2 m.

Clay samples collected in the trenches were sent to Dr. Craig Lake's lab at Dalhousie University to be tested for their suitability for use as a landfill cap or liner. Test results were very favourable. A report documenting this work is in preparation, and should be available for release in 2005.

References

Douglas, G. V. 1944: Ironville limestone deposit; Nova Scotia Department of Mines, Annual Report on Mines for 1943, p. 129-131.

Stea, R. R. and Feetham, M. 2003: Surficial geology map of the Whycocomagh area (NTS 11F/14) Inverness County, Nova Scotia; Nova Scotia Department of Natural Resources, Mineral Resources Branch, Open File Map ME 2003-1, scale 1:50 000.

Digital Information Services

B. E. Fisher, J. C. Poole and J. S. Saunders

The Digital Information Services group is responsible for developing and maintaining the Mineral Resources Branch (MRB) Geographic Information System and associated databases, the NovaScan bibliographic geoscience database, for supplying digital data and services to clients and staff, and for developing and maintaining the MRB Internet web site. Permanent Digital Information Services staff consist of geologists/GIS specialists Brian Fisher and Jeff Poole, and web technicians Susan Saunders and Barbara MacDonald. Jeff McKinnon, a geologist/GIS specialist, was hired as a GIS assistant to work on projects for the federal-provincial Targeted Geoscience Initiative[1] (TGI-2). Sharon Lee, a GIS specialist, was hired in February 2004 and Angie Ehler, a GIS specialist, was hired in October 2004 to work on the TGI-2 project. Paul Barker and Adam Sherry, both geology graduates, were hired to work on the western Nova Scotia mapping projects and the TGI-2 project, respectively. Jie Lu, a computer programmer, was hired in October 2004 to work on the NovaScan database conversion project. Sheri Lyon, Iordana Gardiner, Kathleen Gould and David Hapgood, geology students, were hired to work as GIS assistants during the summer of 2004.

Digital Geoscience Data Products

A collection of digital geology maps, databases and images of Nova Scotia (in DXF, ARC export, ArcView® shapefiles, TIFF, and JPEG formats in a UTM projection using the NAD27 datum, and in PDF format) has been developed, and is available for viewing or free download from the MRB web site (http://www.gov.ns.ca/natr/meb/pubs/pub3.htm). The complete list of digital data products available can be seen in Appendix 3. A licence agreement is issued with all digital data sets. This agreement allows unrestricted use of the data with the understanding that DNR remains the owner of the data and is not transferring copyright to the user. Since March 1999, when data were first made available for download from the MRB web site, there have been over 120,000 downloads.

Public Access GIS

A Public Access GIS has been developed for the use of clients in the DNR Halifax Library. This is a user-friendly query and display system that uses a customized version of ArcView® to access a variety of spatially referenced, digital geoscience data on Nova Scotia. It can display and query data sets, overlay various themes of geoscience, topographic and land-use information, and plot the resulting maps in colour.

GIS Development

Digital Information Services staff have been working cooperatively with MRB staff on several projects, including the Western Nova Scotia Aggregate Project and the Southwest Nova Mapping Project. Paul Barker was hired in January 2004 to digitize and create databases for a number of bedrock and surficial maps required for these compilations.

The GIS version of the Registry of Mineral and Petroleum Titles database was updated several times. Three new versions (12, 13 and 14) of the Mineral Rights Disposition Map for the Province of Nova Scotia (Open File Map ME 2000-6) were released along with three new versions (3, 4 and 5) of the Mineral Rights Database.

Work has continued on converting 48 recently published bedrock geology maps and approximately 30 of the Faribault geological series maps from Fieldlog®/AutoCAD® format into ArcInfo® and incorporating these maps as part of the branch GIS. The maps will be completed and released as digital products in 2005.

[1]For more information about this federal-provincial agreement, see Naylor *et al.*, this volume, p. 69-72.

Fisher, B. E., Poole, J. C. and Saunders, J. S. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 3-6.

Work was completed on a number of shaded relief images of the province. There were a total of 96 images included as part of two digital products (DP ME 56 and 57). An open file map, OFM ME 2004-1 and digital version of it DP ME 105, were produced to explain and describe the use of the shaded relief images and the digital elevation model used to produce them.

In the summer of 2004 a project was begun to develop a new 1:50 000 geology map for NTS area 11D/13. Phase one of this project was to take place during the summer using two students to compile data that were currently available for this map area and put it into a format compatible with our GIS. Work is expected to continue on this project in 2005.

Internet Map Server Applications

Jeff Poole has created several Internet Map Server (IMS) applications that allow our clients to view, query, plot and download digital maps and databases over the Internet. Two applications were released in December 2004 and can be accessed at the following URLs: Nova Scotia Geoscience Maps, Databases and Images at http://gis2.gov.ns.ca/website/nsgeomap; and the Nova Scotia Mineral Resource Land Use Atlas at http://gis2.gov.ns.ca/website/mrlu27.

Targeted Geoscience Initiative Project in Central Nova Scotia

In the fall of 2003 the Geological Survey of Canada (Atlantic) and the Mineral Resources Branch were awarded funding under the Natural Resources Canada Targeted Geoscience Initiative, Phase Two (TGI-2), for a Carboniferous hydrocarbon and mineral potential project in central Nova Scotia. As part of this project we are responsible for producing a digital compilation of geological data for this area. Jeff McKinnon was assigned to work exclusively on this project. Adam Sherry and Dawson Brisco were hired in January 2004 to build databases, digitize maps and develop the digital products that will be produced as a result of this project. In February 2004 Sharon Lee was hired to work on the TGI-2 project. Adam left in August 2004 and Angie Ehler was hired in September 2004 to work on cartographic map production. In June 2004 six digital products (DP ME 97, 111, 113, 117, 118, and 123) containing geophysical images in the TGI-2 area were released. Work continues on 109 open file geophysical maps, four 1:50 000 bedrock maps in the St. Marys Basin, thirteen 1:10 000 maps in the Late Carboniferous areas around Debert; two 1:50 000 bedrock maps for NTS areas 11E/06 and 11E/07, 12 digital products for the bedrock map database, and 15 seismic databases.

Canadian Geoscience Knowledge Network

The Canadian Geoscience Knowledge Network (CGKN) is a collaborative effort between the 12 provincial and territorial geoscience agencies and the Geological Survey of Canada, which operates six offices across Canada. The plan is for the CGKN to be a single window to access geoscience holdings of all the surveys using the Internet. In 2004 the branch continued to develop metadata describing digital data products and publications. The branch received $25,000 funding from CGKN to convert our NovaScan database, currently running on the Unix-based STAR database management system, to SQL Server database management system and make the production of metadata for our NovaScan records part of our business practice.

Digital Products and Open File Maps Released in 2003

The following new digital products, open file maps, and updated versions of digital products were released in 2004. These can all be downloaded for free from the URL listed with the product.

Digital Products

O00-06. Mineral Rights Disposition Map for the Province of Nova Scotia, version 12 (March 1, 2004), version 13 (April 30, 2004), and version 14

(October 4, 2004), compiled by B. E. Fisher and A. S. Wenning, scale 1:500 000. Open File Map ME 2000-6. (http://www.gov.ns.ca/natr/meb/download/00o06.htm)

DP ME 51, Version 3 (March 1, 2004), Version 4 (April 30, 2004) and Version 5 (October 4, 2004), Nova Scotia Mineral Rights Database. Available in E00, SHP and DXF/DBF formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp051.htm

DP ME 56, Version 1, 2004, Shaded Relief Images Derived from a 25 Metre Digital Elevation Model of the Province of Nova Scotia, by B. E. Fisher, J. C. Poole and J. S. McKinnon. Available in MrSID format. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp056.htm

DP ME 57, Version 1, 2004, Shaded Relief Images Derived from a 100 Metre Digital Elevation Model of the Province of Nova Scotia, by B. E. Fisher, J. C. Poole and J. S. McKinnon. Available in JPEG and MrSID formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp057.htm

DP ME 97, Version 1, 2004, Airborne Magnetic Total Field, Calculated First Vertical Derivative and Calculated Second Vertical Derivative Images Collectively Covering NTS Sheets 11E/05, 11E/06, 11E/07, 11E/08, 11E/09, 11E/10, 11E/11, 11E/12, 11E/13, 11E/14, 11E/15, 11E/16, 11F/05, 11F/12, 11F/13, 21H/07, 21H/08, 21H/09, 21H/10 and 21H/16, TGI-2 project, northern mainland Nova Scotia, by M. S. King, 2004. Available in TIFF and JPEG formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp097.htm

DP ME 105, Version 1, 2004, Digital Version of Nova Scotia Department of Natural Resources Open File Map ME 2004-1, Shaded Relief Map of Nova Scotia, scale 1:500 000, 2004, by B. E. Fisher, J. C. Poole, J. S. McKinnon and J. A. Beaumont. Available in PDF format. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp105.htm

DP ME 111, Version 1, 2004, Bouguer Gravity and Residual Bouguer Gravity Images Collectively Covering NTS sheets 11E/01, 11E/02, 11E/03, 11E/04, 11E/05, 11E/06, 11E/07, 11E/08, 11E/09, 11E/10, 11E/11, 11E/12, 11E/13, 11E/14, 11E/15, 11E/16, 11F/04, 11F/05, 11F/12, 11F/13, 21H/01, 21H/02, 21H/07, 21H/08, 21H/09, 21H/10 and 21H/16, TGI-2 project, northern Nova Scotia, by M. S. King, 2004. Available in TIFF and JPEG formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp111.htm

DP ME 113, Version 1, 2004, Airborne VLF-EM Ortho Total Field Images Collectively Covering Parts of NTS Sheets 11E/05, 11E/06, 11E/07, 11E/10, 11E/11, 11E/12, 21H/07, 21H/08, 21H/09 and 21H/10, TGI-2 Project, Cobequid Highlands, Nova Scotia, by M. S. King, 2004. Available in TIFF and JPEG formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp113.htm

DP ME 117, Version 1, 2004, Total Field Airborne Magnetic Images for Individual 1:50 000 NTS sheets 11E/05, 11E/06, 11E/07, 11E/08, 11E/09, 11E/10, 11E/11, 11E/12, 11E/13, 11E/14, 11E/15, 11E/16, 11F/05, 11F/12, 11F/13, 21H/07, 21H/08, 21H/09, 21H/10 and 21H/16, TGI-2 Project, Northern Mainland Nova Scotia, by M. S. King, 2004. Available in TIFF and JPEG formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp117.htm

DP ME 118, Version 1, 2004, Bouguer Gravity and Residual Bouguer Gravity Images for Individual 1:50 000 NTS Sheets 11E/05, 11E/06, 11E/07, 11E/08, 11E/09, 11E/10, 11E/11, 11E/12, 11E/16, 11F/05, 11F/12, 11F/13, 21H/07, 21H/08 and 21H/09, TGI-2 Project, Northern Mainland Nova Scotia, by M. S. King, 2004. Available in TIFF and JPEG formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp118.htm

DP ME 123, Version 1, 2004, Airborne VLF-EM Line Total Field Images Collectively Covering Parts of NTS sheets 11E/02 and 11E/07, TGI-2

Project, Central Nova Scotia, by M. S. King, 2004, Available in TIFF and JPEG formats. Download free from the MRB website at http://www.gov.ns.ca/natr/meb/download/dp123.htm

Open File Maps

OFM ME 2000-6. Mineral Rights Disposition Map for the Province of Nova Scotia, version 12 (X), version 13 (April 20, 2005), version 14 (X), and version 15 (X), compiled by B. E. Fisher and A. S. Wenning, scale 1:500 000.

OFM ME 2004-1, Shaded Relief Map of Nova Scotia, by B. E. Fisher, J. C. Poole, J. S. McKinnon and J. A. Beaumont, 2004, scale 1:500 000, Available in PDF format. Also available as a free PDF download from http://www.gov.ns.ca/natr/meb/download/dp105.htm

NovaScan

NovaScan is the bibliographic geoscience database on Nova Scotia and its offshore regions. As of December 31, 2004, the database contained 14,466 MRB records, consisting of 6886 mineral exploration assessment and property reports, 3750 publications, 2747 open files, 807 theses, 200 contribution series, 58 digital products, and 18 outside publications.

Two hundred ninety-three new records were added to NovaScan in 2004. The new records included 124 assessment and property reports, 72 publications, 28 open files, 6 contribution series, 4 theses, 47 digital publications and 12 outside publications. In 2004, 112 assessment and property reports were publicly released from confidential status.

Each month, a list of open assessment and property reports was generated from NovaScan and distributed to the DNR Library, the Core Library in Stellarton, and to the three Regional Geologists in Coxheath, Bible Hill and Bridgewater along with the microfiche versions of these reports. Quarterly lists of open assessment and property reports were produced and published in the Nova Scotia Minerals Update newsletter.

In 2004 we continued to convert NovaScan records into standard library MARC format, so that they could be loaded into the Provincial Library's Internet-accessible NcompasS catalogue database. This catalogue can be accessed at the following address: http://ncompass.library.ns.ca. After selecting your language of choice (English/French), select Nova Scotia Department of Natural Resources from the available catalogue listings, and you will then be able to search all the DNR Library records, including the NovaScan records. Each month newly released assessment reports, property reports, open files and publications are added to the NcompasS catalogue.

In order to provide better service to our clients the Branch acquired funding from CGKN to convert the NovaScan database from the UNIX-based STAR database management system to the SQL Server database management system. Eventually this will allow clients to search for NovaScan records through either the CGKN metadata catalog or through an Internet-accessible enhanced web search tool that is currently being developed for NovaScan. Both methods of searching the database will allow for spatial searches. Completion of this project should take place in 2005.Upon completion of this project NovaScan records will be removed from the NcompasS catalogue database.

Application of Detailed Ground Magnetic Surveys in an Acid Rock Drainage Study along Highway 101, Lower Sackville to Mount Uniacke (NTS 11D/13), Nova Scotia

R. D. Fitzgerald[1] and T. A. Goodwin

Introduction

Acid rock drainage (ARD) was first identified in Nova Scotia in 1961 when sulphide-bearing Meguma Group rocks exposed in the construction of Halifax International Airport oxidized and lowered the pH of the receiving streams, resulting in a major fish kill between 1957 and 1960 (Environmental Protection Service, 1976). Early studies identified pyrite as the main mineral responsible for ARD in the Meguma Group (Ferguson and Erickson, 1987). Recent study of Halifax Formation slate in central Nova Scotia, however, indicates pyrrhotite is also commonly found within the slate (Zentilli and Fox, 1998; Fox *et al.*, 1997; Haysom *et. al.*, 1997; Fox and Robinson, 1996; King, 1994). Pyrrhotite was found to oxidize faster than pyrite, resulting in rapid generation of ARD (Zentilli and Fox, 1998; Fox *et al.*, 1997; Haysom *et al.*, 1997; Fox and Robinson, 1996).

Previous research has confirmed the presence of pyrrhotite and magnetite (both minerals are magnetic) in metasedimentary rocks of the Meguma Group (Howells and Fox, 1998; King, 1997). Evaluating pyrrhotite concentrations with ground magnetic surveys in the Meguma Group, therefore, may provide a useful tool for planners and developers when assessing the potential for ARD. To date, ARD studies utilizing ground magnetic surveys to evaluate pyrrhotite concentrations in the Meguma Group have been limited to central Nova Scotia (Howells and Fox, 1998; Fox *et al.*, 1997; King, 1997).

Given the distribution of pyrrhotite throughout the Meguma Group, the main objective of this study is to assess the reliability of ground magnetic surveys in locating pyrrhotite-rich rock in the Meguma Group. A further outcome of the study is to better define geologic contacts between the various metasedimentary members of the Meguma Group in the study area, which is characterized by thick till cover.

Study Area

The study area is located in central Nova Scotia between Lower Sackville and Mount Uniacke (NTS 11D/13), approximately 20 km northwest of Halifax (Fig. 1).

Bedrock Geology

The study area is underlain by the Cambro-Ordovician Meguma Group, consisting of two formations (Fig. 2). The Goldenville Formation has an approximate minimum thickness of 5400 m and consists of a thick sequence of grey to greenish-grey metasandstones (Ryan *et al.*, 1996). The Goldenville Formation is conformably overlain by the younger Halifax Formation, which varies in thickness from 500 m to 13 500 m, and consists of dark grey to grey-green slate and metasiltstone (Schenk, 1995).

Goldenville Formation

The Goldenville Formation has been subdivided based on lithology by Ryan *et al.* (1996). The Steve's Road member, which occurs within the study area, is at the top of the Goldenville Formation and is approximately 700 m thick. This

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Fitzgerald, R. D. and Goodwin, T. A. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 7-13.

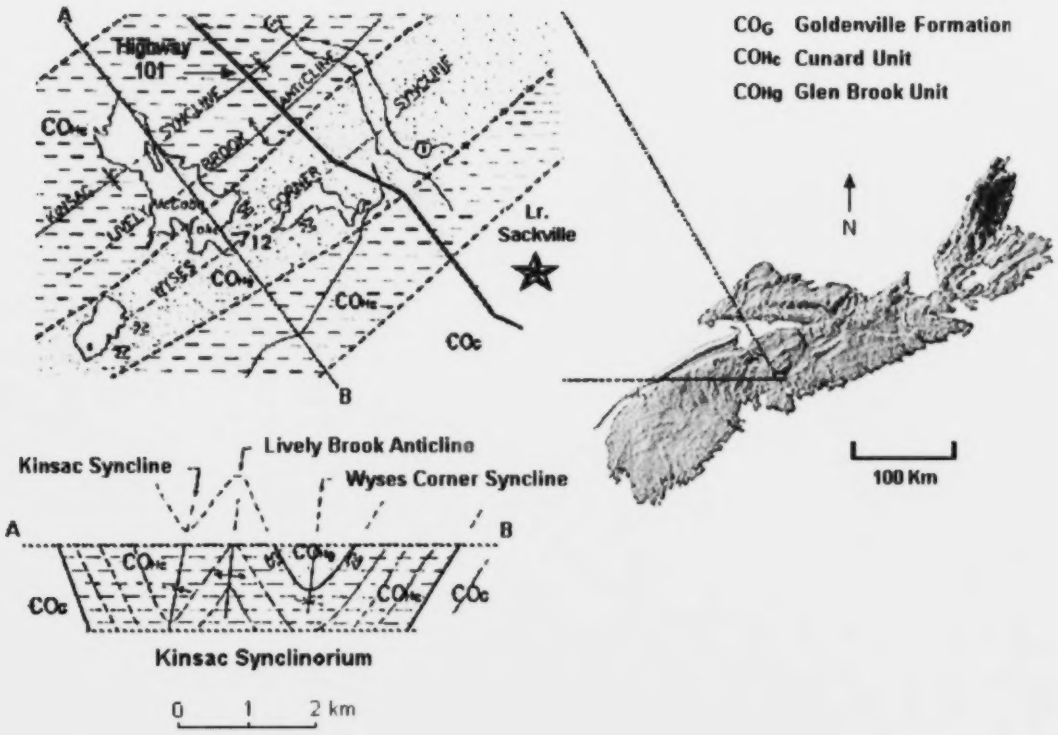


Figure 1. Map of the study area showing bedrock geology and location of the ground magnetic survey line along Highway 101. Profile A-B is a cross section through the Kinsac Synclinorium (revised from Horne *et al.*, 1998).

member consists of medium-grained meta-quartz arenite (metasandstone) and is interbedded with minor metasiltstone and slate. The mineralogy includes trace amounts of sulphide minerals and magnetite (Haysom *et al.*, 1997, Fig. 3). The Goldenville Formation below this unit consists of undivided sandstone, siltstone and slate.

Halifax Formation

Beaverbank Member

The Beaverbank Member represents the basal unit of the Halifax Formation and consists of metasiltstone, silty slate, and meta-quartz arenite (metasandstone) beds (Ryan *et al.*, 1996). It generally fines upward, with decreasing metasandstone towards the top (Ryan *et al.*, 1996), and has been subdivided into the upper beds and lower beds (Fig. 4). It was suggested by Ryan *et al.* (1996) that this member is the equivalent of the Green Bay Formation, as described by O'Brien (1988), which was assessed to have a thickness of 2 km. Coticule zones containing up to 60% spessartine garnet are present in the upper part of this member and are diagnostic features, making it a useful marker horizon. The lower beds contain abundant ilmenite, while the lower section of the upper beds contains abundant pyrite. The top section of the upper beds of this member was found to contain abundant pyrrhotite and pyrite with locally abundant ilmenite (King, 1997; Haysom *et al.*, 1997, Fig. 3).

Cunard Member

Overlying the Beaverbank Member is the Cunard Member. This member consists of finely laminated

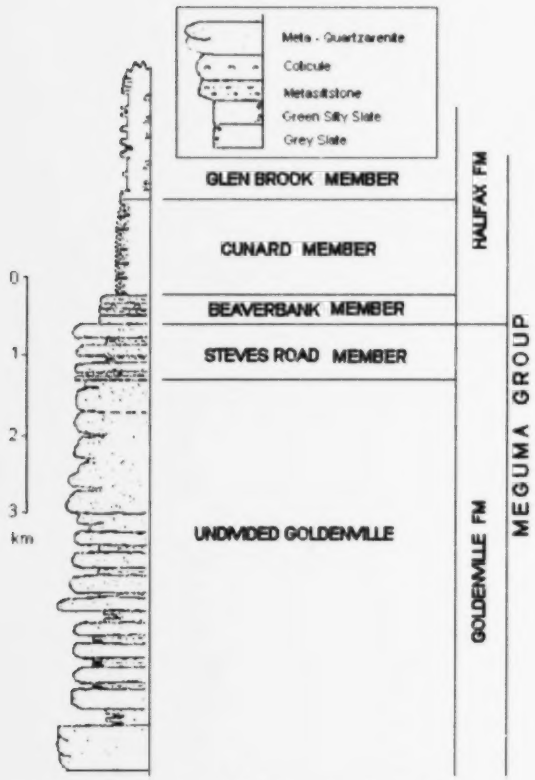


Figure 2. Stratigraphy of the Meguma Group in the study area (modified after Ryan *et al.*, 1996).

grey to black-grey slate, and is approximately 1100 m thick (Ryan *et al.*, 1996).

The Cunard Member (formerly referred to as the Rawdon unit) was further subdivided by Horne (1995) into subunits "a" and "b" (Fig. 3). King (1997) describes subunit "a" as having abundant pyrrhotite and also containing pyrite, biotite, chlorite and minor ilmenite. He further describes subunit "b" as having abundant ilminite and containing rutile and chlorite, with trace amounts of pyrite. The Cunard Member is further characterized by a distinctive high magnetic signature (King, 1997; Ryan *et al.*, 1996), with subunit "a" having the highest content of sulphides (> 5%; Haysom *et al.*, 1997).

Glen Brook Member

The Glen Brook Member conformably overlies the Cunard Member (Fig. 3). In the study area, this member contains thinly banded greenish-grey metasiltstone and rare metasandstone beds (Horne *et al.*, 1998). This member is approximately 1900 m thick in the Rawdon Syncline area (Ryan *et al.*, 1996) and contains only trace amounts of sulphide minerals (Haysom *et al.*, 1997). King (1997) describes the Glen Brook Member as containing abundant ilmenite, biotite, and chlorite, which may affect its magnetic character.

Ground Magnetic and Chip Sampling Survey

An EG & G Geometrics Model G-856A magnetometer was used to acquire the ground magnetic data for this study. Total field magnetic readings were recorded approximately every 12.5 m for a total of 538 stations.

The magnetic survey followed a 10 km line parallel to Highway 101 (Fig. 1). The entire line was surveyed over a period of several days. A new base station was established daily for each line segment and diurnal variations were observed and corrections made for on a daily basis. At each station the total field magnetic readings were recorded along with UTM coordinates. Descriptive comments, including the presence of outcrop, guardrails, logging roads, ATV trails and garbage, were recorded. The line was oriented perpendicular to the regional structure and crossed all members of the Meguma Group on both sides of the Kinsac Syclinorium (Fig. 1).

Once the ground magnetic survey was completed, the plotted results were used in combination with observed outcrop locations to determine optimum rock sampling site locations. Outcrops were revisited and 5 kg samples of composite rock chips were collected for future geochemical analysis. The sampling program was designed to ensure that the rock samples collected were representative of each member in the study area. Fourteen rock samples were collected along the entire length of the line (Figs. 4 and 5). The sampling stations were selected to: (1) give stratigraphic representation, (2) give spatial representation over the length of the survey line, and (3) systematically sample representative members of variable magnetic intensities.

In some instances, there were no outcrops along the survey line available to sample for certain members (e.g. Beaverbank Member). Samples,

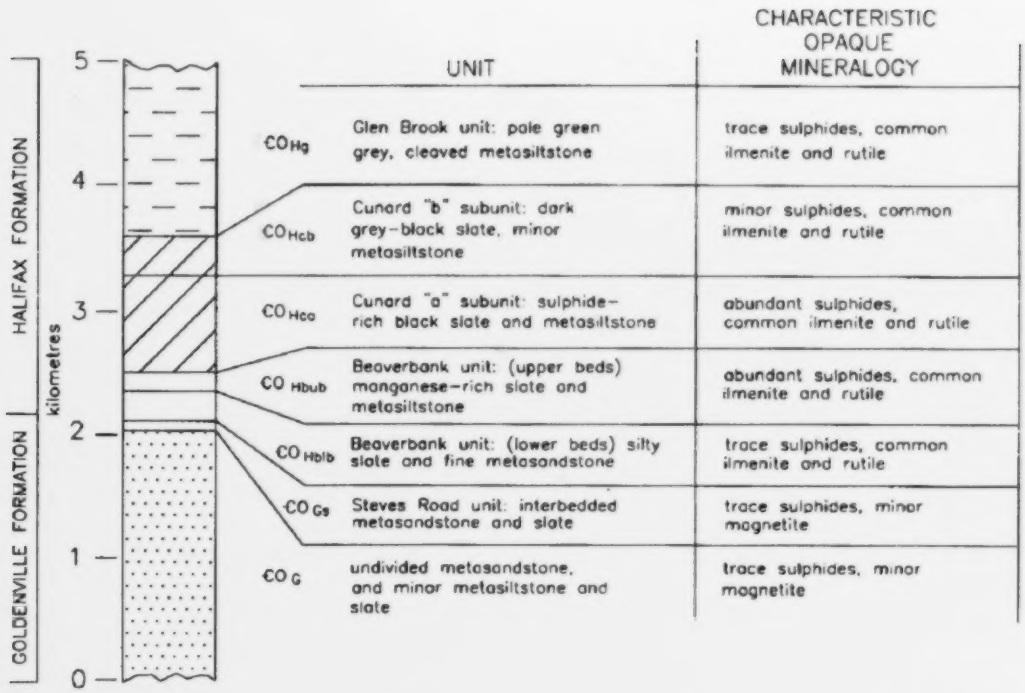


Figure 3. Revised stratigraphy of the Meguma Group in central Nova Scotia, with subdivision of the Beaverbank Member and abundance of sulphide minerals (modified after Haysom *et al.*, 1997).

therefore, were collected from nearby outcrops located off the survey line but estimated to be as close as possible to the same stratigraphic level.

Results

Total field magnetic results for the entire line are presented as a line graph in Figure 4 and as an x-y scattergram in Figure 5. The plotted data in both graphs have been corrected for diurnal variations and for cultural effects (e.g. culverts, power lines). These cultural effects produced spurious low readings and have been removed from Figures 4 and 5. Stations that were characterized by the highest magnetic readings were revisited in the field. Outcrops at these locations were tested with a hand-held magnetic susceptibility meter and numerous thin beds were identified as having extremely high magnetic susceptibilities. These outcrops were further characterized by their rusty iron-stained appearance. Fresh samples contained abundant sulphides, dominated by pyrrhotite (approximately 5%, visual estimation). A hand magnet and hand lens were used to support the observation that the chief sulphide mineral was pyrrhotite. Cultural effects were not observed at any of these sites; therefore, the high total field magnetic readings were presumed to be caused by the presence of pyrrhotite in bedrock. This demonstrates that the magnetometer can be used to locate pyrrhotite-rich beds and can be used as a predictive tool in ARD studies.

The proposed geologic contacts presented in Figure 5 take into consideration previous bedrock mapping (Horne *et al.*, 1998; Ryan *et al.*, 1996; Ryan, 1995), mineralogical investigations (Haysom *et al.*, 1997; Fox and Robinson, 1996; Fox *et al.*, 1997; King, 1994, 1997; Zentilli and Fox, 1998), evaluation of aeromagnetic data (King, 1994, 1997), and our field observations.

Discussion

The highest magnetic measurements in the study

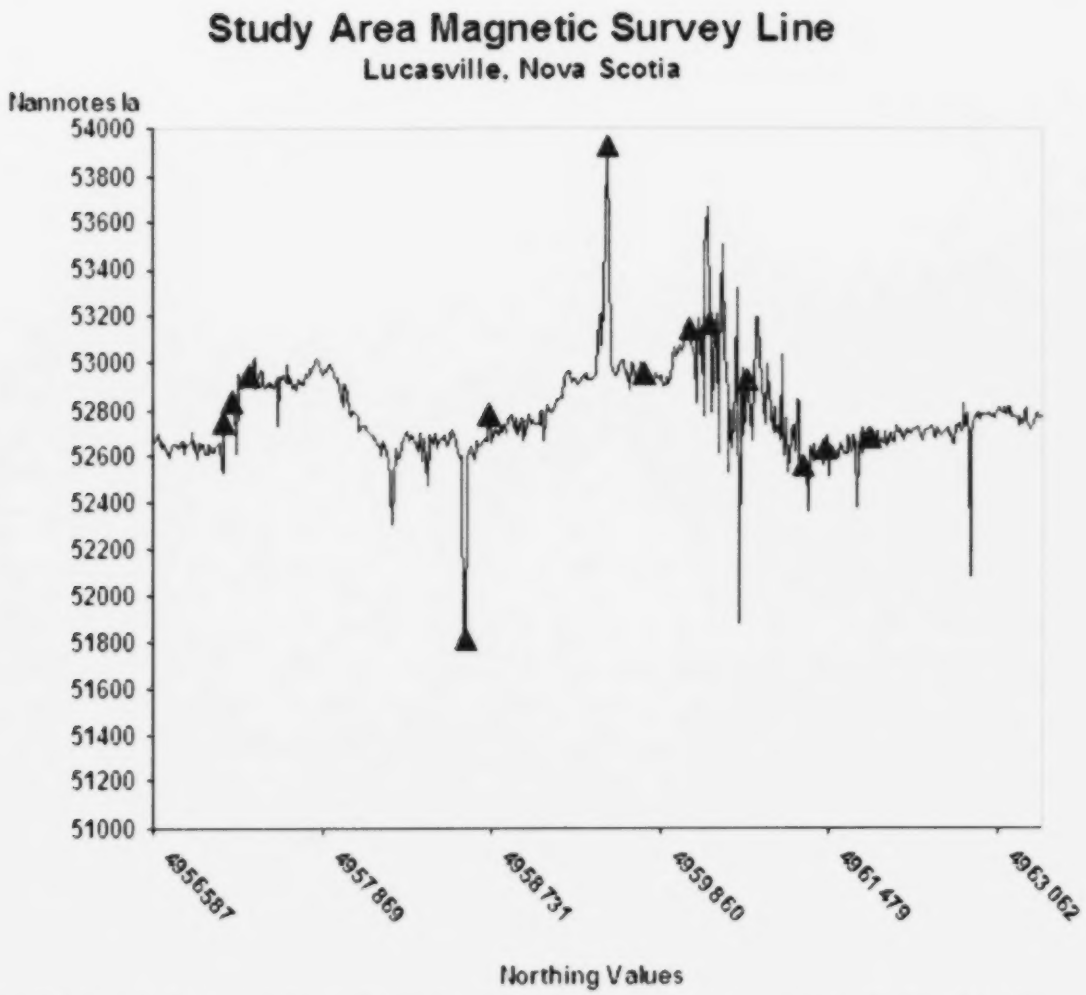


Figure 4. Line graph of corrected magnetic survey readings with corresponding selected sample locations, which are represented by triangles.

were from the pyrrhotite-rich Cunard Member. This was closely followed by the Beaverbank Member, which also contains locally abundant sulphides, dominated by pyrrhotite.

In the field, these two members were characterized by their red rusty appearance, the presence of sulphides, and their high magnetic susceptibilities. Therefore, these two members are likely to generate problems with respect to acid rock drainage when exposed to oxidizing conditions.

The Glen Brook Member, the Steve's Road Member, and the undivided Goldenville Formation are characterized by low ground magnetic readings, negligible to trace sulphide content, and low magnetic susceptibility readings. These three members, therefore, are less likely to contribute in the generation of ARD when exposed to oxidizing conditions.

Figures 4 and 5 show a rising magnetic response of the Goldenville Formation on the north end of the survey line. This may be attributed to the presence of magnetite in a thermal aureole associated with intrusion of the South Mountain Batholith (McGrath, 1970), which outcrops approximately 2 km to the north.

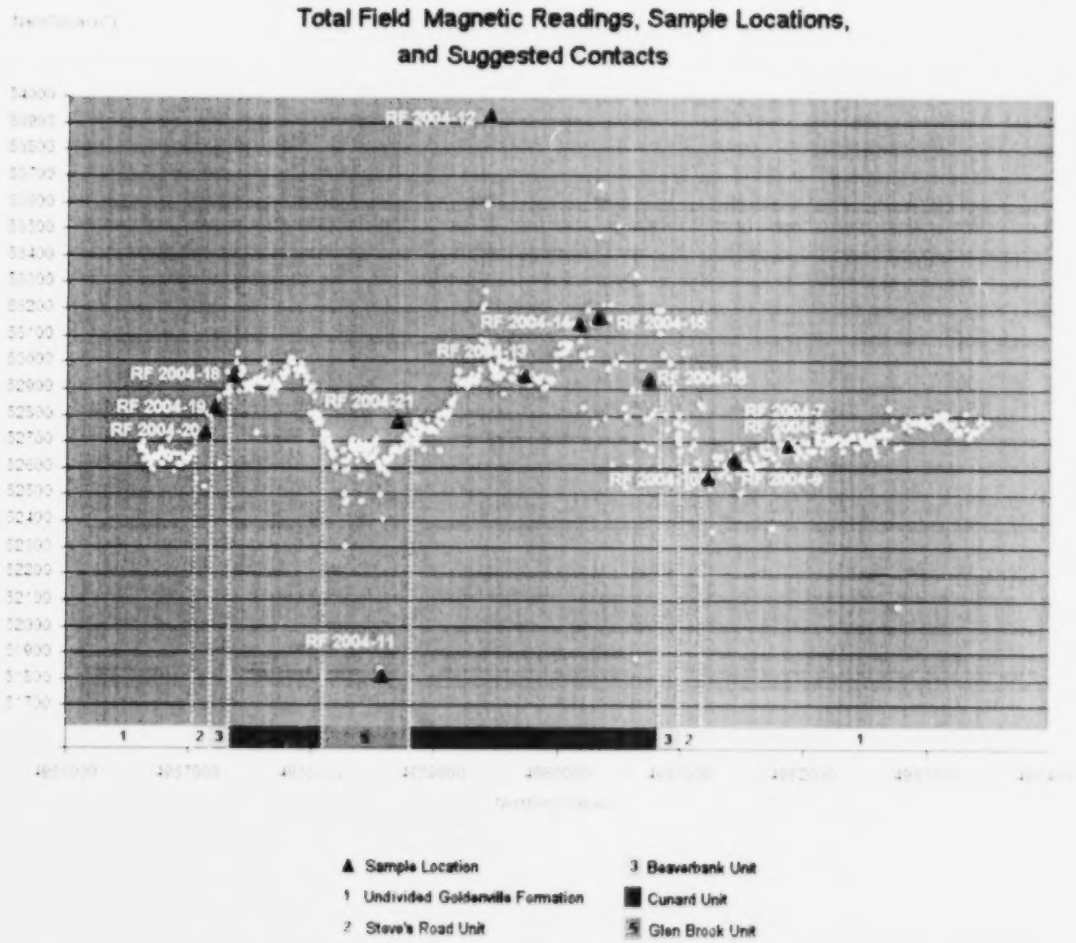


Figure 5. Corrected Total Field magnetic results for the Highway 101 line along with proposed contacts of members within the study area. Rock samples collected from outcrops are represented as triangles.

References

Ashfield, D., Farmer, G. J., Macphail, D. K. and Mandell, P. 1984: Chemical characteristics of selected rivers in Nova Scotia and New Brunswick: Canadian Data Report of Fisheries and Aquatic Sciences No. 489, 18 p.

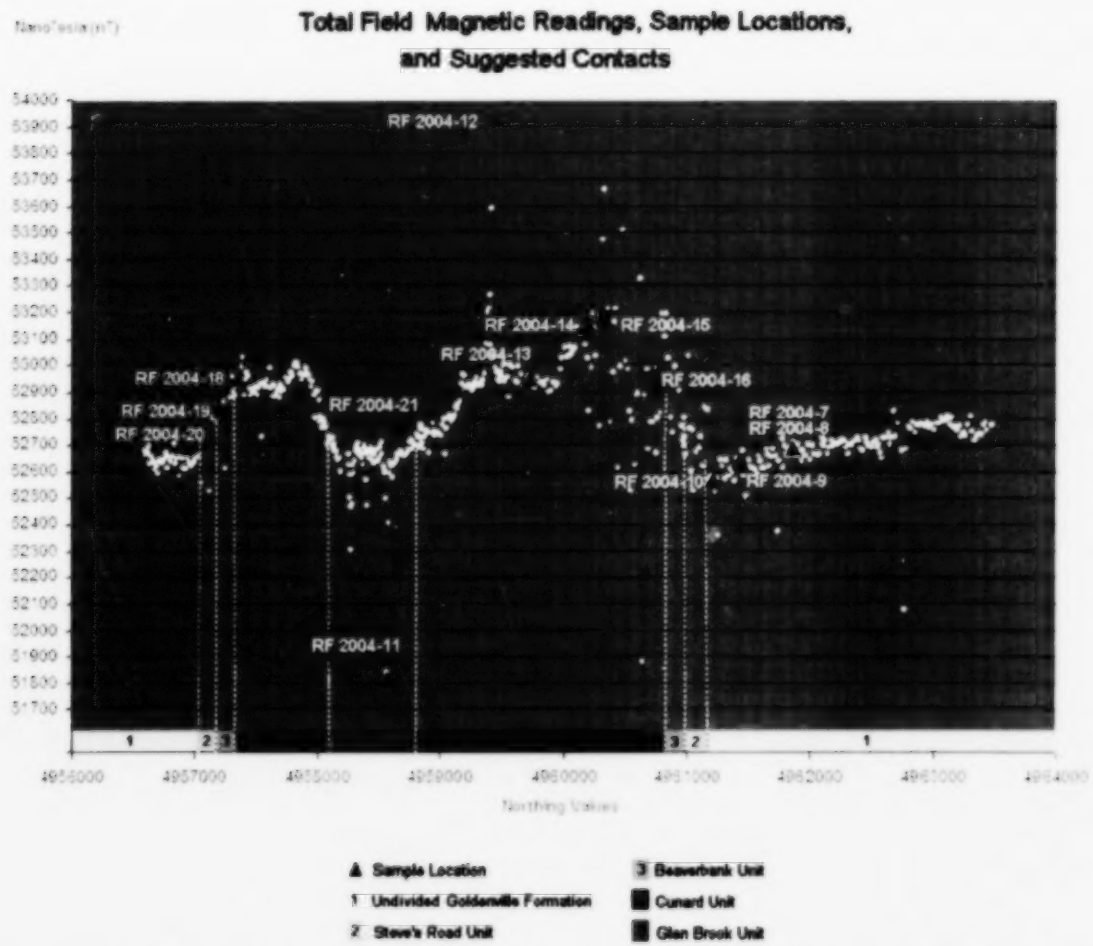
Environmental Protection Service (ESB - Atlantic Region) 1976: A report on the causes of fish kills in the Shubenacadia River at Enfield, Nova Scotia.

Ferguson, K. D. and Erickson, P. M. 1987: Will it generate AMD?: Proceedings, Acid Mine Drainage Seminar Workshop, Halifax, Nova Scotia, March 23-26, 1987, Environment Canada, p. 245-261.

Fox, D. and Robinson, C. 1996: Predicting acid drainage from rocks of the Halifax Formation, Meguma Group, Nova Scotia: Atlantic Geology (Abstract), v. 32 (1), p. 69.

Fox, D., MacInnis, L. Knee, K., Zentilli, M. and Graves, M. 1995: Acid drainage from black slates of the Halifax Formation: is there need for further work?: Atlantic Geology (Abstract), v. 31 (1),p. 45.

Fox, D., Robinson, C. and Zentilli, M. 1997: Pyrrhotite and associated sulphides and their



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Ashfield, D., Farmer, G. J., Macphail, D. K. and Mandell, P. 1984: Chemical characteristics of selected rivers in Nova Scotia and New Brunswick; Canadian Data Report of Fisheries and Aquatic Sciences No. 489, 18 p.

Environmental Protection Service (ESB - Atlantic Region) 1976: A report on the causes of fish kills in the Shubenacadia River at Enfield, Nova Scotia.

Ferguson, K. D. and Erickson, P. M. 1987: Will it generate AMD?; Proceedings, Acid Mine Drainage Seminar/Workshop, Halifax, Nova Scotia, March 23-26, 1987, Environment Canada, p. 245-261.

Fox, D. and Robinson, C. 1996: Predicting acid drainage from rocks of the Halifax Formation, Meguma Group, Nova Scotia; Atlantic Geology (Abstract), v. 32 (1), p. 69.

Fox, D., MacInnis, I., Knee, K., Zentilli, M. and Graves, M. 1995: Acid drainage from black slates of the Halifax Formation: is there need for further work?; Atlantic Geology (Abstract), v. 31 (1),p. 45.

Fox, D., Robinson, C. and Zentilli, M. 1997: Pyrrhotite and associated sulphides and their

relationship to acid rock drainage in the Halifax Formation; Atlantic Geology, v. 33, p. 87-103.

Horne, R. J. 1993: Preliminary report on the geology of the Rawdon area; *in* Mines and Minerals Branch, Report of Activities 1992, eds. D. R. MacDonald and K. A. Mills; Nova Scotia Department of Natural Resources, Report 93-1, p. 61-67.

Horne, R. J. 1995: Update on bedrock mapping of the Rawdon Syncline; *in* Minerals and Energy Branch, Report of Activities 1994, eds. D. R. MacDonald and K. A. Mills; Nova Scotia Department of Natural Resources, Report 95-1, p. 57-61.

Horne, R. J. and Macdonald, L. A., 1998: Geological map of Lucasville (part of NTS sheet 11D/13), Halifax County, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 1998-007, scale 1:10 000.

Horne, R. J., Macdonald, L. A., Bhatnagar, P. and Tèniére, P. 1998: Preliminary bedrock geology of the Lucasville-Lake Major area, Central Meguma mapping project, central Nova Scotia; *in* Minerals and Energy Branch, Report of Activities 1997, eds. D. R. MacDonald, and K. A. Mills; Nova Scotia Department of Natural Resources Report 98-1: p. 15-24.

Haysom, S., Horne, R. J. and Pe-Piper, G. 1997: The opaque mineralogy of metasedimentary rocks of the Meguma Group, Beaverbank - Rawdon area, Nova Scotia; Atlantic Geology, v. 33, p. 105-120.

Howells, K. and Fox, D. 1998: Geophysical methods for detecting shallow sulphide mineralization in the Halifax Formation, Nova Scotia: a reconnaissance study; Atlantic Geology, v. 34, no. 3, p. 211-227.

King, M. S. 1994: Magnetic mineralogy and susceptibility of north – central Meguma Group: implications for the interpretation of aeromagnetic total field, first derivative, and second derivative; Nova Scotia Department of Natural Resources, Mines and Energy Branches, Open File Report 94-004, 38 p.

King, M. S. 1997: Magnetic susceptibility mapping: applications for the Meguma Group, central Nova Scotia; Atlantic Geology, v. 33, p. 121-131.

McGrath, P. H. 1970: Aeromagnetic interpretation, Appalachia, New Brunswick and Nova Scotia (11D, E, F, K; 20O, P; 21A, G, H, J); Geological Survey of Canada, Paper 70-1A, p. 79-82.

Ryan, R. J. 1995: Update on Meguma Group mapping and economic geology as part of a multi-disciplinary study of the central Meguma area, Nova Scotia; Mineral and Energy Branch Report of Activities 1994, eds. D. R. MacDonald and K. A. Mills; Nova Scotia Department of Natural Resources, Report 95-1, p. 53-56.

Ryan, R. J., Fox, D., Horne, R. J., Corey, M. C., and Smith, P. K. 1996: Preliminary stratigraphy of the Meguma Group in central Nova Scotia; *in* Mines and Minerals Branch Review of Activities, eds. D. R. MacDonald and K. A., Mills; Nova Scotia Department of Natural Resources Report 96-1, p. 27-34.

Schenk, P. E. 1995: Meguma Zone; Chapter 3 of the Appalachian-Caledonian orogen of Canada and Greenland, ed. H. Williams; *in* Geological Survey of Canada, Geology of Canada, v. 6, p. 261-277.

Thompson,B. D.1978: An investigation of Meguma bedrock leaching in the Shubie – Stewiacke River basin; prepared for the Shubenacadie – Stewiacke River Basin Board, 45 p.

Zentilli, M. and Fox, D. 1998: Geology and mineralogy of the Meguma group and their importance to environmental problems in Nova Scotia; Atlantic Geology, Special Issue, v. 33 (2), p. 81-85.

Nova Scotia Gold Grain Study: Background and Anomalous Concentrations of Gold Grains in Till

T. A. Goodwin

Introduction

Regional till sampling programs have been routinely undertaken throughout most of Canada by various levels of government and, of course, mineral exploration companies in their search for gold, diamonds and other minerals of economic importance. As a result of these programs, background concentrations of gold recovered from the heavy mineral concentrate (HMC) from 10 kg till samples are known for many terranes. For example, background concentrations of gold grains in till from across the Abitibi Greenstone Belt range from <1 gold grain in the north to about 10 gold grains in the south (McClenaghan, 2001).

Besides the frequency of occurrence, the gold grain morphology can also be used to estimate the distance of glacial transport from its bedrock source. The morphology of the gold grains recovered from till samples is, generally, classed into three categories: pristine, modified and reshaped (DiLabio, 1990). Pristine grains are indicative of minimal transport from source, ranging from 0 to 100 m, modified gold grains have been glacially transported in the order of 500 m, while reshaped grains have been displaced in excess of 1000 m from source. There are, of course, exceptions (Henderson and Roy, 1995).

Companies engaged in diamond exploration programs use a similar methodology for the recovery and identification of kimberlite indicator minerals (KIMs), kimberlite being the host rock of diamond deposits. The relative abundances of KIMs recovered in till samples are used as indicators of proximity to source, recognizing that individual kimberlite mineralogy varies significantly (McClenaghan and Kjarsgaard, 2001). Similarly, surface features and textures observed on KIMs recovered from the HMC of till samples provide similar clues to the distance of transport. For example, the presence of kelyphite rims on Cr-pyrope grains provides some indication of the relative distance of transport, as does the presence of orange peel texture (McClenaghan and Kjarsgaard, 2001).

To date, there has been no regional evaluation of gold grain concentrations in till for the Meguma Terrane of Nova Scotia. There are, however, very few property-scale studies available that involve the identification and morphological classification of gold grains recovered from till samples. One of these studies involved a reverse-circulation drilling program conducted to map the distribution of gold in the till profile at the Beaver Dam Gold District (Duncan, 1987).

There have also been several studies involving the collection and electron microprobe analysis of gold grains recovered from till from several gold districts within Nova Scotia (MacEachern, 1983; MacEachern and Stea, 1985). The morphological character and composition of individual gold grains recovered from these studies led to the conclusion that there was little evidence of abrasive glacial transport because of the rough, pitted and delicate edges of the gold grains.

During the 2004 field season, twenty 10 kg till samples were collected in order to determine: (1) background concentrations of gold grains from across the province, (2) anomalous gold grain concentrations and the associated dispersal pattern within a known gold district (Beaver Dam) and (3) the morphology of each of the grains recovered, providing an estimate for the distance of glacial transport.

Regional Geology

Bedrock Geology

Mainland Nova Scotia south of the Cobequid-Chedabucto Fault Zone lies within the Meguma Terrane (Fig. 1), which is dominated by the Meguma Group, a 9000 m thick succession of siliciclastics that host most of Nova Scotia's gold deposits (Ryan and Smith, 1998). The Meguma Group consists of two formations: the basal metasandstone-dominated Goldenville Formation, which is conformably overlain by slate and meta-

Goodwin, T. A. 2005. *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 15-26.

siltstone with minor metasandstone of the Halifax Formation (Ryan and Smith, 1998). The Meguma Group metasediments were subsequently intruded by Devonian granitoids, namely granodiorite, monzogranite and leucomonzogranite (MacDonald and Horne, 1987).

Most gold occurrences tend to be spatially associated with thicker than normal slate (argillite) beds interstratified with Goldenville Formation metasandstones (Sangster, 1990). Gold generally occurs in qaurtz veins on the crests and flanks of regional anticlines or domal structures within a gold district, which can measure up to 4 km long and up to 0.5 km wide (Sangster, 1990). Quartz is the dominant vein mineral but carbonates also commonly occur as do lesser amounts of sulphides, such as pyrite, pyrrhotite, arsenopyrite, galena, chalcopyrite and sphalerite (Ryan and Smith, 1998). Arsenopyrite characterizes all the gold districts in variable amounts up to a maximum of about 5%. It is most abundant in wall rocks but also occurs in quartz veins (Sangster, 1990).

Gold in Nova Scotia

The first vein-hosted gold discovery in the Meguma Terrane occurred at Mooseland in 1858 by Lieutenant C. L'Estrange while hunting moose (Malcolm, 1929). This led to a major gold rush for Nova Scotia and by the beginning of the Twentieth Century, the Government of Nova Scotia recognized 60 gold districts throughout the province. Production continued relatively unabated until the beginning of the Second World War in 1939. Since 1939, only limited, sporadic production has occurred, except from 1983 to 1987 when a federal exploration incentive, coupled with relatively steady gold prices, allowed for some consistent production (Ryan and Smith, 1998). For historical and descriptive geological details, Malcolm (1929) summarizes the first 70 years of gold exploration and mine development in the Meguma Terrane of Nova Scotia. Bates (1987) summarizes the historical milling methods used to crush the gold ore, gold extraction methodologies, and historical production from the gold districts.

Bedrock Geology and Mineralization, Beaver Dam Gold District

The Beaver Dam gold deposit is located on the south, overturned limb of the northeast-trending Beaver Dam-Fifteen Mile Stream anticline (Ryan and Smith, 1998). At the district scale, gold occurs in high-grade quartz veins and as disseminated gold in slate beds within the Goldenville Formation metasandstones (Ryan and Smith, 1998). The mineralized zone is displaced by the Mud Lake Fault to the east and by the River Lake Pluton to the west (Coker *et al.*, 1988).

Beaver Dam, like many other gold districts in the Meguma Terrane, is characterized by a thicker than normal package of slate (argillite) beds interstratified with the dominant metasandstones (Sangster, 1990). The slate package consists of the Crouse Argillite, Papke Argillite and the Austen Argillite interstratified with the Hanging Wall Greywacke and the Millet Seed Greywacke (Sangster, 1990). The package has an average thickness of approximately 150 m, of which slate (argillite) constitutes approximately 75% of the total thickness, or about 105 m (Sangster, 1990). Gold occurs in all three slate (argillite) units; however, recent (mid-1980s) underground development primarily focused on the Papke and Austin zones (Ryan and Smith, 1998). A detailed summary of the stratigraphy, mineralization and alteration of the Beaver Dam Gold District is provided by Duncan (1987).

Additionally, numerous small quartz veins hosted in several 3 m thick (average) slate belts are known to contain gold. Unveined slate belts further characterized by the presence of arsenopyrite are also known to contain discrete grains of gold. Grades in these belts vary from 0.5 to 2.5 g Au/t over widths of 5 to 15 m (Ryan and Smith, 1998).

Accessory minerals may include variable amounts of pyrrhotite, galena, sphalerite, chalcopyrite, scheelite, stibnite, argentite, tetrahedrite, loellingite, molybdenite and tellurides (Sangster, 1990). Highly variable silica enrichment visually characterizes the Beaver Dam deposit (Kontak and Smith, 1987).

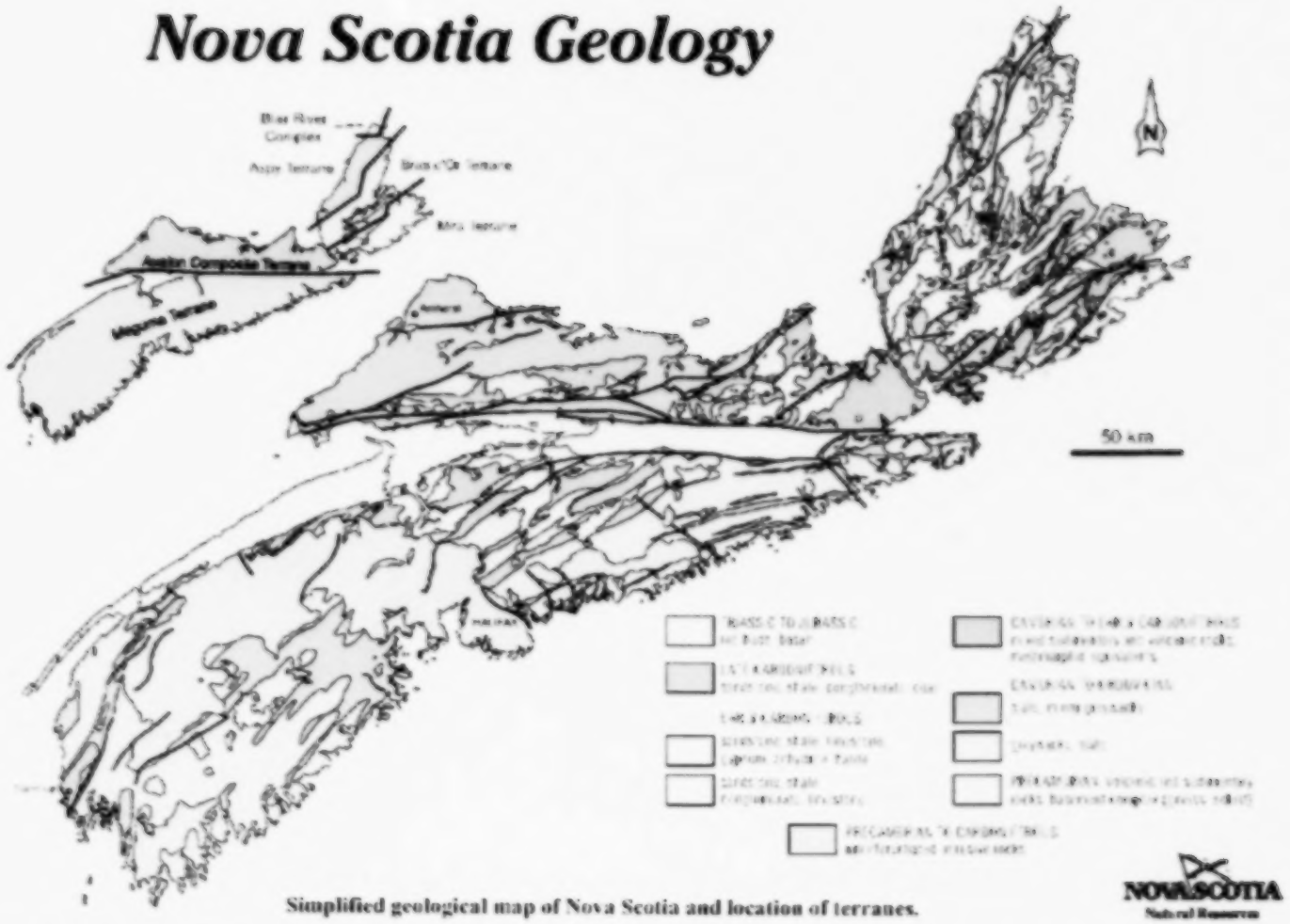
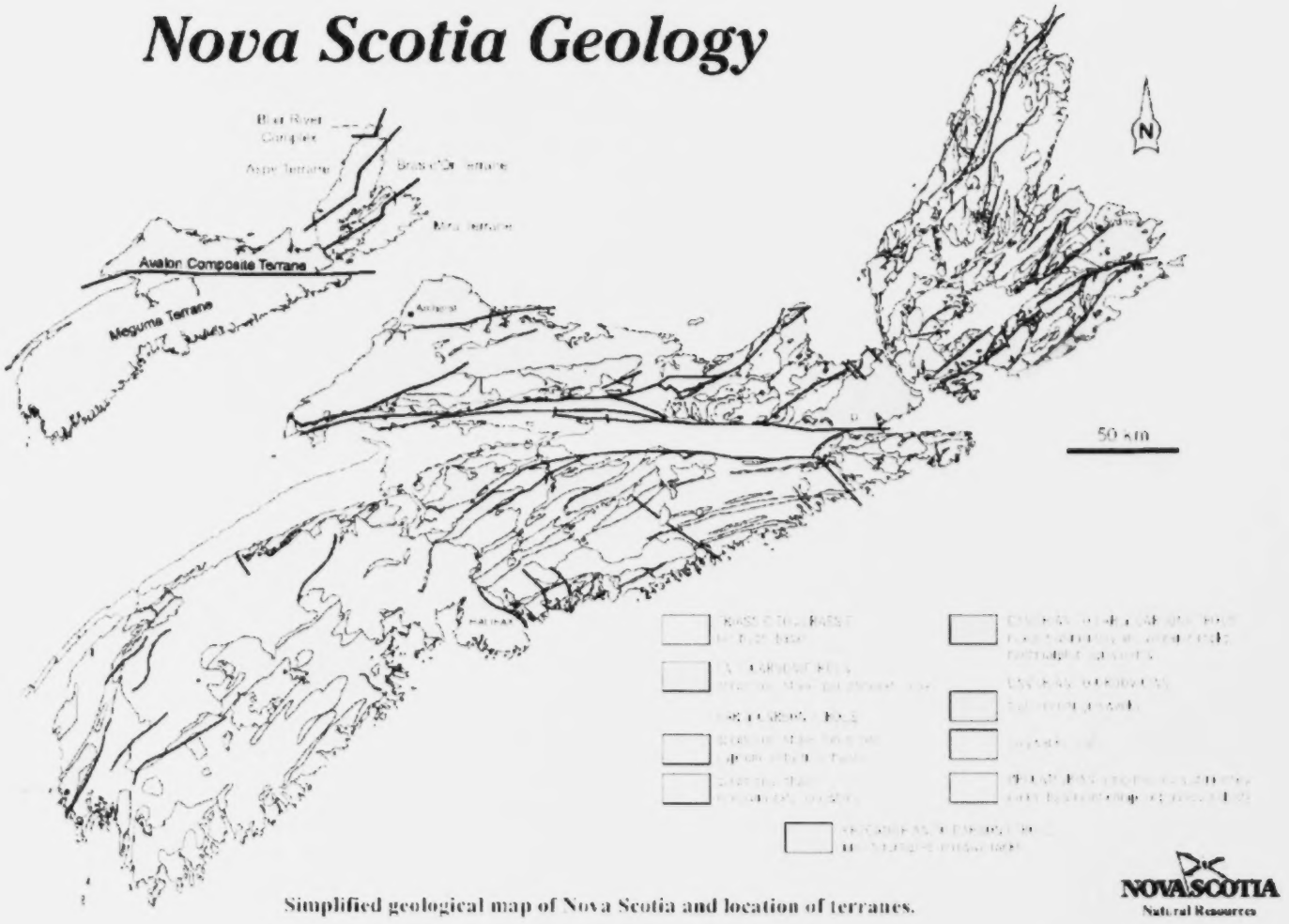


Figure 1. Simplified geological map of Nova Scotia. Inset shows the locations of terranes. The Cobequid-Chedabucto Fault Zone separates the Meguma Terrane to the south from the Avalon Composite Terrane to the north.



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History of Gold Exploration and Production, Beaver Dam Gold District

Gold was first reported from the Beaver Dam Gold District in 1868. By 1871 the first 15 stamp mill was erected and two zones of quartz veins were explored (Malcolm, 1929).

Historical production of gold recovered from quartz veins at the Beaver Dam Gold District between 1890-1906 totalled 966 ounces of gold (Sangster, 1990). Malcolm (1929) describes additional exploration and limited production work until the end of 1926. A resurgence in Meguma gold exploration during the 1980s resulted in the production of an additional 11,859 ounces of gold (Sangster, 1990), a portion of which was mined from Beaver Dam.

A detailed summary on the exploration history of the Beaver Dam Gold District is available in Duncan (1987).

Surficial Geology

Generally, most of the surficial deposits and associated landforms throughout Nova Scotia were formed during the Wisconsinan glaciation in the last 70 000 years (Lewis *et al.*, 1998). Superimposed till sheets and various multiple-flow directional indicators have been mapped and indicate that Nova Scotia is characterized by a relatively complex ice flow history (Stea *et al.*, 1992; Stea and Finck, 2001).

The oldest observed ice flow indicators on land show movement toward the east and southeast. This ice flow is responsible for the formation of the Hartlen Till and has been called the Caledonia Phase (75-40 ka). South and southwest flow of the Escuminac Phase (22-18 ka) followed and is responsible for deposition of the Lawrencetown Till. The Scotian Phase (18-15 ka), characterized by an ice divide, affected most of Nova Scotia and the resulting ice flow varied from northwestward in northern Nova Scotia to south and southeast in southern Nova Scotia, followed by the formation of the Beaver River Till. The Chignecto Phase (13-12.5 ka) was characterized by shifting ice flow associated with several small ice caps, the remnants of waning stages of the Scotian Phase glacier (Stea and Finck, 2001).

Enrichment of gold and arsenic, with lesser enrichment of copper, lead, zinc, tungsten, bismuth, tellurium and iron, characterize the bedrock geology of many of the gold deposits of the Meguma Terrane (Kontak and Smith, 1993). These elements are commonly geochemically enriched in soil and till down-ice from known gold occurrences, resulting from mechanical dispersion (erosion, transportation and deposition) by advancing glacial ice (Coker *et al.*, 1988). Glacial dispersal distances vary in Nova Scotia from hundreds of metres to several kilometres down-ice from source (Stea and Finck, 2001).

Surficial Geology, Beaver Dam Gold District

The Beaver Dam Gold District is characterized by relatively thin till (<5 m), although locally it can reach thicknesses of 25 m or more (Coker *et al.*, 1988). The till is characterized by the locally derived Quartzite Till of Stea and Fowler (1979). The Quartzite Till is now referred to as the Beaver River Till, metagreywacke (or metasandstone) facies (Finck and Stea, 1995).

Coker *et al.* (1988) indicate the dominant ice flow direction in the Beaver Dam Gold District is toward the southeast (145) and this is also the youngest ice flow event recorded in the district (Coker *et al.*, 1988). The oldest recorded ice flow direction, however, is toward the south (180) with an intermediate ice flow toward the east (090 , Coker *et al.*, 1988).

Methodology

Introduction

During the 2004 field season, fourteen regional C-horizon till samples were collected from randomly selected sites across mainland Nova Scotia (Fig. 2). Most samples were collected from the Meguma Terrane, from which 1,198,619 troy ounces of gold were produced from over 50 gold districts (Bates, 1987). The samples were collected in order to determine background regional gold grain counts for a 10 kg till sample. The fourteen sample sites were chosen to provide (1) a broad aerial

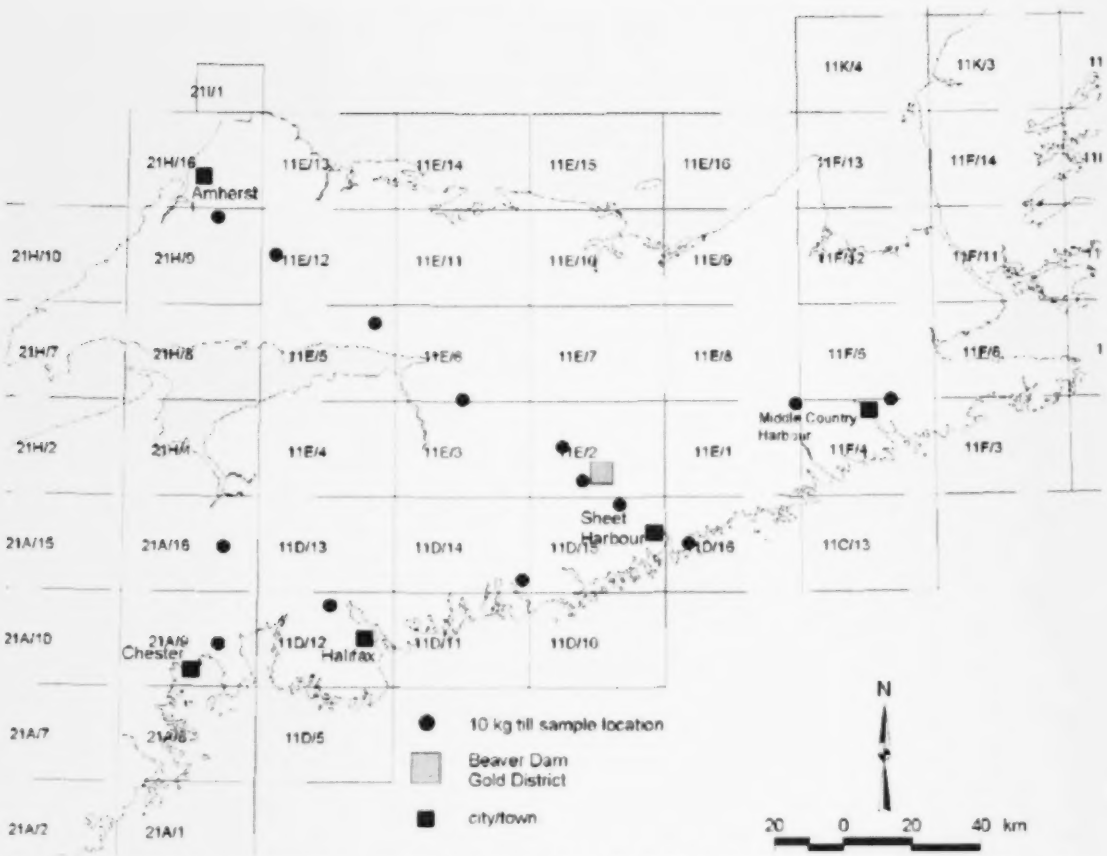


Figure 2. Regional till sample location map. Detailed till samples collected from the Beaver Dam Gold District. Note: All regional till samples reported 0 to 3 gold grains per 10 kg sample.

distribution across mainland Nova Scotia, (2) representative coverage of the major surficial units and (3) easy access by taking advantage of pre-existing roads.

In addition to the fourteen regional samples, six detailed samples were collected from the Beaver Dam Gold District, located along the Eastern Shore of Nova Scotia, approximately 100 km northeast of Halifax (Fig. 2). The samples were collected on a single northwest-southeast line approximately 1400 m in length in order to determine the effects of glacial dispersal on gold grain counts and grain morphology across the Beaver Dam Gold District, and to quantify the dispersal pattern (Fig. 3). The Beaver Dam Gold District was selected because previous geochemical sampling of soil and till identified a well defined, 300 m long dispersal train evident in various sample media immediately down-ice from the Mill Shaft (Coker *et al.*, 1988). Of particular interest to the 2004 gold grain study was the gold anomaly identified in the heavy mineral concentrate of till by Coker *et al.* (1988). The six detailed till samples collected in 2004 were oriented along the previously identified dispersal train, with sampling extended approximately 200 m up-ice from the Mill Shaft and 800 m down-ice beyond the south shore of Crusher Lake. The outer bark scales of red spruce also define a gold and arsenic dispersion train, as well as a currently unknown area of anomalous gold content up-ice from the Mill Shaft (Dunn *et al.*, 1991).

Detailed field descriptions were recorded at each sample site and a digital photograph was taken for future reference. Notes regarding each sample site included sample depth, till type, colour, texture, and clast type and percentage were

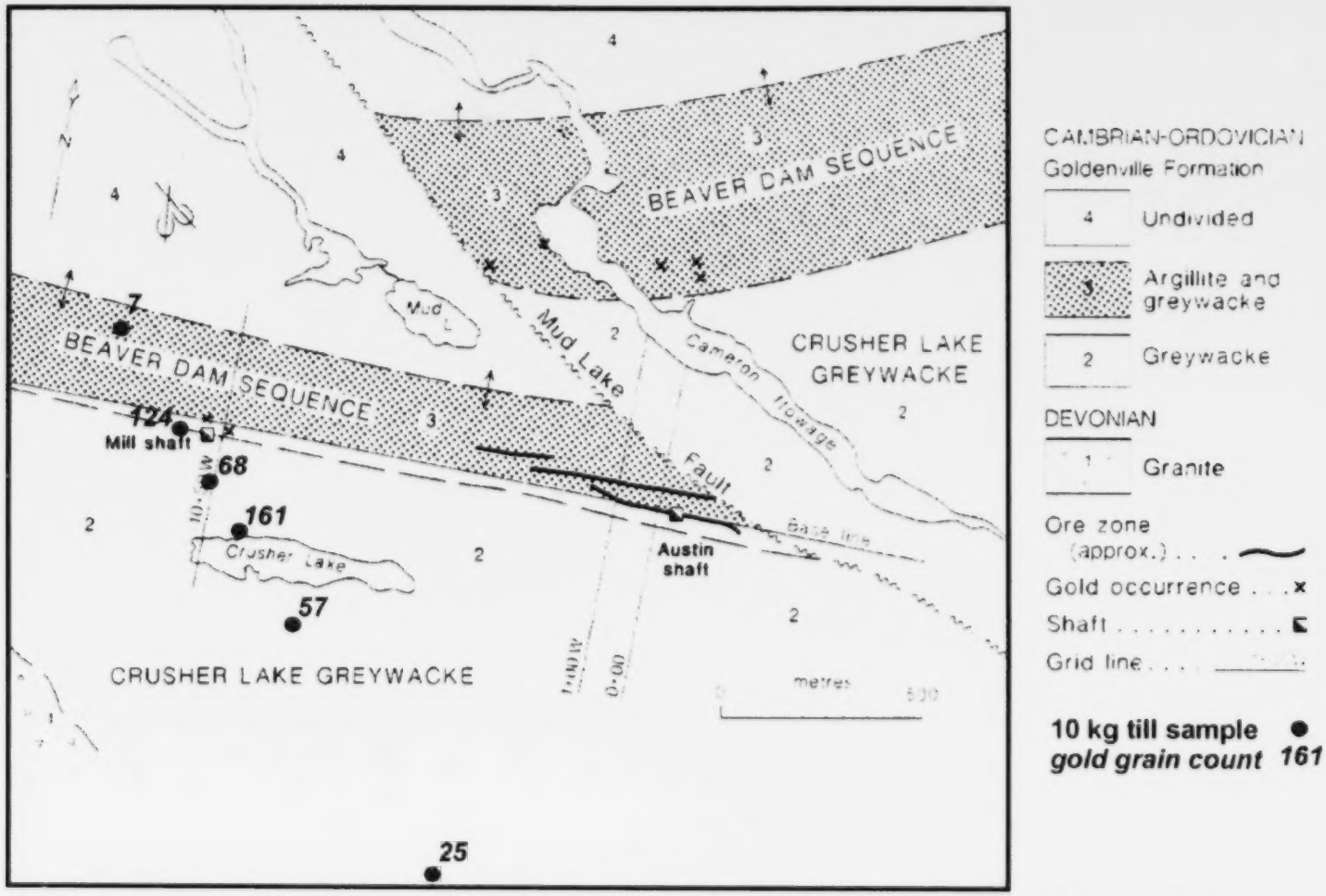


Figure 3. Detailed till sample locations and corresponding gold grain counts for the Beaver Dam Gold District. Modified from Coker *et al.* (1988).

recorded. Sample sites were geo-referenced (NAD 27) to the Universal Transverse Mercator (UTM) grid using the averaging function of a GARMIN 12 GPS (Table 1).

Field Sampling Methodology

A 10 kg till sample was collected at each sample site. Regional samples were typically collected from approximately 1.5 to 2.5 m depth along roadside till exposures. Samples for the detailed sampling program at Beaver Dam were from hand-dug till pits between 1.0 and 1.5 m deep. All samples were collected by shovel and were passed through a 1 cm plastic sieve in the field prior to placement into a 4 mil plastic bag. A fish scale was used to weigh each sample to ensure a minimum of 10 kg of till was collected from each site. The >1 cm clast fraction was washed, clast lithotypes were identified (metasandstone, slate/argillite, quartz vein, granite, Carboniferous sediments or Cobequid Highlands intrusives/volcanics) and estimates of the percentage of each type were recorded in the field.

Laboratory Preparation and Analytical Methodology

All samples collected during the 2004 field season were sent to Overburden Drilling Management (ODM) Limited of Nepean, Ontario. Upon arrival, ODM produced a 30 g sub-sample of the <63 micron size fraction, which was forwarded to ACME Analytical Laboratories of Vancouver, British Columbia, for Au (+ 51 element ICP-MS) analysis for comparison of the geochemical signature with the gold grains recovered, as well as previous multi-element geochemistry reported by Coker *et al.*, 1988.

Overburden Drilling Management processed the 10 kg till samples for the recovery of a heavy mineral concentrate (HMC), gold grain counts, gold morphology description, and >2 mm clast recovery. The >2 mm fraction was removed by wet screening while the <2 mm fraction was preconcentrated by density separation while being passed across a shaking table, and visible gold grains were identified and counted. The >2 mm fraction was subsequently placed into pre-labelled bags for future lithologic identification.

Where necessary, the table concentrate was also (micro) panned and an additional gold grain count was performed. The table concentrate was then subjected to a heavy liquid separation in methylene iodide (S. G. 3.3). A ferromagnetic separation was performed on the resulting HMC and the non-magnetic HMC was weighed and placed into pre-labelled vials.

Overburden Drilling Management recorded sample weights after each processing stage and all material was retained for future reference. All equipment was thoroughly cleaned between samples. ODM is recognized for their ability to recover and describe gold grains from glacial sediments.

Geochemical analysis for gold in the HMC was not completed as part of this study. Estimates of the calculated visible gold grade of the HMC, however, were provided by ODM.

Results

Results of the background and anomalous gold grain counts and associated gold grain morphologies for 10 kg till samples collected from throughout mainland Nova Scotia and from within the Beaver Dam Gold District are being reported here for the first time (Table 2). Table 3 summarizes the tabling and heavy liquid separation test weight results.

Regionally, background gold grain counts for mainland Nova Scotia range from 0 to 3 gold grains (the majority of which were reshaped grains) per 10 kg of till (Table 2). Specifically, the NW-SE profile line from Amherst to Sheet Harbour reported 0 to 1 gold grain per 10 kg till sample. Similarly, 0 to 3 gold grains characterize 10 kg till samples collected from Chester in southwestern Nova Scotia to Middle Country Harbour along the Eastern Shore of mainland Nova Scotia.

Results from the detailed 10 kg till sampling program in the Beaver Dam Gold District indicate gold grain concentrations increase from a minimum of 7 gold grains approximately 250 m up-ice from the Mill Shaft to a maximum of 161 gold grains approximately 300 m down-ice from the shaft. Gold grain counts drop off to 25 gold grains per 10 kg till sample approximately 1200 m down-ice from the Mill Shaft. The gold grain morphologies that characterize the 10 kg till samples collected

Table 1. Till samples with UTM (NAD27) co-ordinates.

SAMPLE #	utm-E27	utm-N27	Comments	Bedrock Geology
GGS2004-01	409562	4940203	regional sample	monzogranite
GGS2004-02	411031	4968490	regional sample	granodiorite
GGS2004-03	480438	5010920	regional sample	Horton Group siliciclastics
GGS2004-04	509664	4997257	regional sample	Meguma Group, metasandstone
GGS2004-05	515634	4987435	regional sample	Meguma Group, metasandstone
GGS2004-06	526350	4980317	regional sample	Meguma Group, metasandstone
GGS2004-07	546244	4969166	regional sample	Meguma Group, metasandstone
GGS2004-08	409507	5064008	regional sample	Cumberland Group, sediments
GGS2004-09	426323	5053164	regional sample	Cumberland Group, sediments
GGS2004-10	454929	5033188	regional sample	Cumberland Group, sediments
GGS2004-11	605036	5011393	regional sample	Meguma Group, metasandstone
GGS2004-12	577139	5009852	regional sample	Meguma Group metasandstone
GGS2004-13	521162	4990014	Beaver Dam sample	Meguma Group, metasandstone
GGS2004-14	521083	4990121	Beaver Dam sample	Meguma Group, metasandstone
GGS2004-15	521010	4990217	Beaver Dam sample	Meguma Group, metasandstone
GGS2004-16	520894	4990399	Beaver Dam sample	Meguma Group, metasandstone
GGS2004-17	521281	4989744	Beaver Dam sample	Meguma Group, metasandstone
GGS2004-18	521602	4989187	Beaver Dam sample	Meguma Group, metasandstone
GGS2004-19	497826	4958441	regional sample	Meguma Group, metasandstone
GGS2004-20	441929	4951184	regional sample	Meguma Group, metasandstone

from the Beaver Dam study area indicate the majority of the gold grains (>80%) are dominated by pristine and modified gold grains, indicating proximity to source (Table 2). Plotted results show a classic head and tail dispersal pattern down-ice from the known gold deposit associated with the Mill Shaft (Fig. 4). There is a corresponding increase in the percentage of reshaped gold grains in the tail position.

Routine pebble estimates were made in the field for all sample locations. Quantitative counts will be performed on the > 2 mm size fraction sometime in the near future.

The potential of the Beaver River Till to host an economic source of gold in the Tangier Gold District is currently being evaluated (Stea *et al.*, this volume, p. 101-115). Gold grains recovered from 10 kg till samples and geochemical analysis of gold in till indicate the till is characterized by anomalous gold concentrations. The Tangier study will further assess the amount, distribution and morphological character of gold recovered from till from in the district.

Conclusions

Regional background gold grain counts for 10 kg till samples collected across mainland Nova Scotia range from 0 to 3 gold grains. Detailed 10 kg till samples collected along a profile line near the Mill

Table 2. Summary of the number of recovered visible gold grains and the calculated content (ppb) of visible gold in the heavy mineral concentrate (HMC).

Sample Number	Number of Visible Gold Grains				Non-magnetic HMC Weight	Calculated ppb visible gold in HMC			
	Total	Reshaped	Modified	Pristine	(g)	Total	Reshaped	Modified	Pristine
GGS2004-01	0	0	0	0	6.5	0	0	0	0
GGS2004-02	0	0	0	0	6.3	0	0	0	0
GGS2004-03	1	0	1	0	14.3	13	0	13	0
GGS2004-04	1	1	0	0	15.9	5	5	0	0
GGS2004-05	0	0	0	0	14.0	0	0	0	0
GGS2004-06	0	0	0	0	38.8	0	0	0	0
GGS2004-07	1	1	0	0	17.3	11	11	0	0
GGS2004-08	1	1	0	0	1.4	58	58	0	0
GGS2004-09	1	1	0	0	16.6	12	12	0	0
GGS2004-10	0	0	0	0	21.5	0	0	0	0
GGS2004-11	3	3	0	0	98.2	17	17	0	0
GGS2004-12	3	1	2	0	19.0	13	10	3	0
GGS2004-13	161	4	43	114	13.2	2710	93	834	1783
GGS2004-14	68	6	16	46	11.1	7989	7198	219	573
GGS2004-15	124	5	37	82	12.0	10498	825	1273	8399
GGS2004-16	7	0	3	4	17.1	30	0	17	12
GGS2004-17	57	3	20	34	13.2	1110	146	717	247
GGS2004-18	25	5	6	14	14.1	118	48	30	39
GGS2004-19	2	0	0	2	8.7	4	0	0	4
GGS2004-20	3	0	1	2	2.8	117	0	29	88

Shaft, located in the Beaver Dam Gold District, indicate gold grain counts range from a low of 7 gold grains approximately 250 m up-ice from the Mill Shaft to a maximum of 161 gold grains approximately 300 m down-ice from the Mill Shaft. The last sample collected 1200 m down-ice from the Mill Shaft contained 25 gold grains recovered from a 10 kg till sample. The gold grains exhibit a classic head and tail dispersal train (Fig. 4).

The morphologies of the majority of the gold grains recovered from the regional sampling program indicate most grains are reshaped, indicating the grains have probably travelled a minimum distance of 1000 m from source. Conversely, the grain morphologies of the vast majority of the gold grains recovered from the Mill Shaft area are pristine (<100 m of glacial transport) and modified (<500 m of glacial transport), suggesting proximity to source.

Additional regional sampling of till is required to confirm background levels for mainland Nova Scotia and Cape Breton Island. Additional sampling at Beaver Dam is also required up-ice from the Mill Shaft until background gold grain counts (3 gold grains or less for a 10 kg till sample) are encountered. Similarly, additional down-ice sampling of till is also required to establish the dispersal length of the anomaly, currently 1400 m long but still open to the south.

Table 3. Summary of the sample weights at the various processing stages.

Sample Number	Weight (kg)				Weight (g) dry				
					-2.0 mm Heavy Liquid Separation (S.G. 3.3)				
							HMC		
	Bulk Rec'd	Table Spill	+2.0 mm Clasts	Table Feed	Table Conc	Lights	Total	Non Mag	Mag
GGS2004-01	9.8	9.0	1.7	7.3	311.2	303.6	7.0	6.5	0.5
GGS2004-02	10.7	9.9	1.6	8.3	351.7	343.6	6.9	6.3	0.6
GGS2004-03	13.5	12.7	2.0	10.7	308.1	291.9	15.1	14.3	0.8
GGS2004-04	10.4	9.6	2.1	7.5	264.7	247.1	16.6	15.9	0.7
GGS2004-05	10.4	9.6	3.7	5.9	325.8	310.1	15.0	14.0	1.0
GGS2004-06	10.3	9.6	2.3	7.3	281.6	239.7	41.2	38.8	2.4
GGS2004-07	10.9	10.1	1.4	8.7	179.2	160.0	18.5	17.3	1.2
GGS2004-08	10.4	9.6	0.2	9.4	264.5	262.5	1.5	1.4	0.1
GGS2004-09	10.6	9.8	0.9	8.9	227.5	209.8	17.1	16.6	0.5
GGS2004-10	11.4	10.8	3.7	7.1	336.2	31.5	25.1	21.5	3.6
GGS2004-11	10.9	10.1	1.8	8.3	279.5	178.6	100.6	98.2	2.4
GGS2004-12	11.4	10.8	2.6	8.2	278.6	257.5	21.0	19.0	2.0
GGS2004-13	9.3	8.6	1.7	6.9	254.7	240.2	13.4	13.2	0.2
GGS2004-14	10.7	9.9	2.0	7.9	219.1	204.1	11.2	11.1	0.1
GGS2004-15	10.4	9.7	3.3	6.4	279.5	265.5	12.5	12.0	0.5
GGS2004-16	13.0	12.2	5.7	6.5	181.2	163.2	17.4	17.1	0.3
GGS2004-17	12.1	11.3	2.0	9.3	254.8	241.5	13.6	13.2	0.4
GGS2004-18	12.5	11.8	2.3	9.5	208.3	193.2	14.3	14.1	0.2
GGS2004-19	10.1	9.3	2.4	6.9	283.9	272.6	10.5	8.7	1.8
GGS2004-20	10.4	9.6	3.7	5.9	347.7	343.8	3.1	2.8	0.3

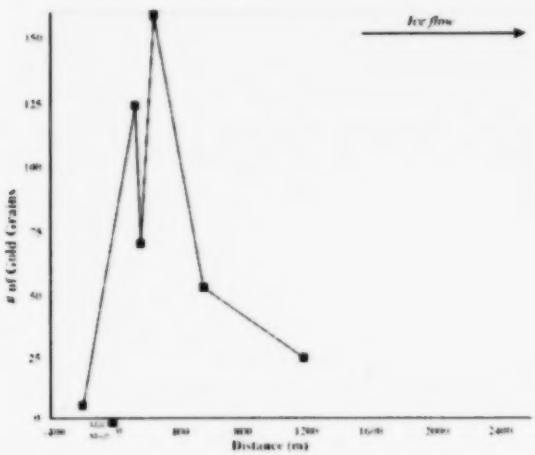


Figure 4. Down-ice dispersal of gold grains recovered from 10 kg till samples from the Beaver Dam Gold Disrtrict

References

Bates, J. L. E. 1987: Gold in Nova Scotia; Nova Scotia Department of Mines and Energy, Information Series No. 13, 48 p.

Coker, W. B., Sexton, A., Lawyer, I. and Duncan, D. 1988: Bedrock, till and soil geochemical signatures at the Beaver Dam gold deposit, Nova Scotia, Canada; *in* Prospecting in Areas of Glaciated Terrain – 1988, eds. D. R. MacDonald and K. A. Mills; Proceedings of Symposium sponsored by Canadian Institute of Mining and Metallurgy, Halifax, NS, 1988, p. 241–254.

DiLabio, R. N. W. 1990: Classification and interpretation of the shapes and surface textures of gold grains from till on the Canadian Shield; *in* Current Research, Part C, Geological Survey of Canada Paper 88-1C, p. 61-65.

Duncan, D. R. 1987: Assessment Report on 1987 Exploration Program on Development License 0078, Halifax County, Nova Scotia, NTS: 11E/2A; Nova Scotia Department of Natural Resources, Assessment Report AR87-117, 41 p.

Dunn, C. E., Coker, W. B. and Rogers, P. J. 1991: Reconnaissance and detailed geochemical surveys for gold in eastern Nova Scotia using plants, lake sediment, soil and till; Journal of Geochemical Exploration, v. 40, p. 143-163.

Finck, P. W. and Stea, R. R. 1995: The compositional development of tills overlying the South Mountain Batholith; Nova Scotia Department of Natural Resources, Mines and Minerals Branch, Paper 95-1, 51 p.

Henderson, P. J. and Roy, M. 1995: Distribution and character of gold in surface till in the Flin Flon greenstone belt, Saskatchewan; *in* Current Research 1995-E, Geological Survey of Canada, p. 175-186.

King, M. S. 1994: Magnetic mineralogy and susceptibility of the north-central Meguma Group: implications for the interpretation of aeromagnetic total field, first derivative, and second derivative; Nova Scotia Department of Natural Resources, Open File Report 94-004, 40 p.

Kontak, D. J. and Smith, P. K. 1987: Alteration haloes and their implications for gold mineralization in the Meguma Zone, Nova Scotia; *in* Report of Activities 1987; Nova Scotia Department of Mines and Energy, Report 87-1, p. 65-74.

Kontak, D. J. and Smith, P. K. 1993: A metaturbidite-hosted lode gold deposit: the Beaver Dam deposit, Nova Scotia; I. vein paragenesis and mineral chemistry; Canadian Mineralogist, v. 31, p 471-522.

Lewis, C. F. M., Taylor, B. B., Stea, R. R., Fader, G. B. J., Horne, R. J., MacNeill, S. G. and Moore., J. G. 1998: Earth science and engineering: urban development in the metropolitan Halifax region; *in* Urban Geology of Canadian Cities, eds. P. F. Karrow and O. L. White, Geological Association of Canada, Special Paper 42, p. 409-444.

MacDonald, M. A. and Horne, R. J. 1987: Geological map of Halifax and Sambro; Nova Scotia Department of Mines and Energy, Map 87-6, scale 1:50 000.

MacEachern, I. J. 1983: The distribution, character and composition of gold in till at the Fifteen Mile Stream Gold District, Halifax County, Nova Scotia; Unpublished B.Sc. Thesis, Dalhousie University, Halifax, 63 p.

MacEachern I. J. and Stea R. R. 1985: The dispersal of gold and related elements in tills and soils at the Forest Hill gold district, Guysborough County, Nova Scotia; Geological Survey of Canada, Paper 85-18, 31 p.

Malcolm, W. 1929: Gold Fields of Nova Scotia; Geological Survey of Canada, Memoir 156, 253 p.

McClenaghan, M. B. 2001: Regional and local-scale gold grain and till geochemical signatures of lode Au deposits in the western Abitibi Greenstone Belt, central Canada; *in* Drift Exploration in Glaciated Terrain, eds. M. B. McClenaghan, P. T. Bobrowsky, G. E. M. Hall and S. J. Cooke; Geological Society of London, Special Publication 185, p. 201-224.

McClenaghan, M. B. and Kjarsgaard, B. A. 2001: Indicator mineral and geochemical methods for diamond exploration in glaciated terrain in Canada; *in* Drift Exploration in Glaciated Terrain, eds. M. B. McClenaghan, P. T. Bobrowsky, G. E. M. Hall and S. J. Cooke; Geological Society of London, Special Publication 185, p. 83-123.

O'Brien, B. H. 1983: The structure of the Meguma Group between Gegogan Harbour and Country Harbour, Guysborough County; *in* Mines and Minerals Branch, Report of Activities, 1982, ed. K. A. Mills; Nova Scotia Department of Mines and Energy, Report 83-1, p. 145-181.

Ryan, R. J. and Smith, P. K. 1998: A review of mesothermal gold deposits of the Meguma Group, Nova Scotia, Canada; *in* Ore Geology Reviews 13, Nos. 1-5, eds. W. R. H. Ramsay, F. P. Bierlein and D. C. Arne, p. 153-183.

Sangster, A. L. 1990: Metallogeny of the Meguma Terrane, Nova Scotia; *in* Mineral Deposit Studies in Nova Scotia, Volume 1, ed. A. L. Sangster; Geological Survey of Canada, Paper 90-8, p. 115-162.

Smith, P. K. 1983: Geology of the Cochrane Hill Gold Deposit, Guysborough County, Nova Scotia; *in* Mines and Minerals Branch, Report of Activities 1982, ed. K. A. Mills; Nova Scotia Department of Mines and Energy, Report 83-1, p. 225-256.

Smith, P. K. and Kontak, D. J. 1988: Meguma gold studies II: vein morphology, classification and information, a new interpretation of 'crack-seal' quartz veins; *in* Mines and Minerals Branch, Report of Activities 1987, Part B, eds. D. R. MacDonald and Y. Brown; Nova Scotia Department of Mines and Energy, Report 88-1, p. 61-76.

Stea, R. R., Conley, H. and Brown, Y. (compilers) 1992: Surficial geology of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Map ME 92-3, scale 1:500 000.

Stea, R. R. and Finck, P. W. 2001: An evolutionary model of glacial dispersal and till genesis in Maritime Canada; *in* Drift Exploration in Glaciated Terrain, eds. M. B. McClenaghan, P. T. Bobrowsky, G. E. Hall and S. J. Cook; Geological Society of London, Special Publication 185, p. 237-265.

Stea, R. R. and Fowler, J. H. 1979: Pleistocene geology, Eastern Shore region, Nova Scotia (sheets 1-3), scale 1:100 000; *in* Minor and Trace Element Variations in Wisconsinan Tills, Eastern Shore Region, Nova Scotia; Nova Scotia Department of Mines and Energy, Paper 79-4, 30 p.

Multi-element Distribution in Humus, Soil and Till Associated with the Upper and Lower Seal Harbour Gold Districts (NTS 11F/04)

T. A. Goodwin

Introduction

Field work associated with the second year of a three-year multi-disciplinary project, initiated in the spring of 2003 as part of the Geological Survey of Canada's Metals in the Environment (MITE) Program, was completed during the summer of 2004. The main objective of the MITE project is to examine the distribution of metals in the environment associated with past-producing gold districts throughout the province by characterizing regional and local background concentrations and speciation of the elements. Further, it is anticipated that off-site transport of the elements from mine waste such as tailings and waste rock dumps, and the transformation and fate of these elements in receiving environments, can be quantified.

During the period from 1862 to 1982, 1,198,619 troy ounces of gold were produced from over 50 gold districts (Bates, 1987) in Nova Scotia. After crushing in a stamp mill, the gold was recovered from the host rock using one of three extraction methods: (1) gravity separation, (2) cyanidation and (3) mercury (Hg) amalgamation. Historical records suggest that up to 25% of the mercury added during the amalgamation process was routinely lost to the tailings and/or to the atmosphere (Eaton, 1978).

In May 2003, ten past-producing gold districts were chosen for the initial stage of reconnaissance level, multi-media sampling and subsequent evaluation (Goodwin *et al.*, 2003). These sites were selected and prioritized on the basis of the following criteria: (1) known history of Hg amalgamation; (2) extensive tailings deposits and (3) little or no previous environmental work available. After sampling each of the ten districts during the 2003 field season, the Upper and Lower Seal Harbour gold districts were chosen for detailed follow-up work during the 2004 field season.

Bedrock Geology

Southern Nova Scotia is part of the Meguma Terrane, which is in part defined by the Meguma Group, a 9000 m thick succession of siliciclastics that hosts most of Nova Scotia's gold deposits (Ryan and Smith, 1998). The Meguma Group consists of two formations: the basal metasandstone-dominated Goldenville Formation which is conformably overlain by slate and meta-siltstone of the Halifax Formation (Ryan and Smith, 1998).

Polyphase deformation characterizes the Meguma Group rocks. The rocks form a series of tight, upright, variably plunging, northeasterly trending, asymmetric folds (Ryan and Smith, 1998). Numerous structural elements define the complex deformation of the eastern part of the Meguma Group (O'Brien, 1983; Smith, 1983). Regional greenschist to lower amphibolite facies metamorphism characterizes the Meguma Group rocks (Ryan and Smith, 1998).

Folded Meguma Group metasediments were intruded by Devonian granitoids, including granodiorite, monzogranite and leucomonzogranite (MacDonald and Horne, 1987). Contact metamorphic minerals near the voluminous granitoid intrusions include biotite, andalusite, cordierite, staurolite and sillimanite (Ryan and Smith, 1998).

Lode-gold occurs within numerous vein types, mainly in rocks associated with the Goldenville Formation. The veins generally occur on the crests and flanks of regional anticlines and domes that measure up to 4 km long and up to 0.5 km wide within a gold district (Sangster, 1990). The nature and classification of veins in the Meguma Group strata have been summarized by Smith and Kontak (1988).

Quartz is the dominant vein mineral but carbonates also commonly occur. Associated

Goodwin, T. A. 2005. *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 27-33.

sulphides include pyrite, pyrrhotite, arsenopyrite, galena, chalcopyrite and sphalerite (Ryan and Smith, 1998). Most gold occurrences tend to be spatially associated with thicker than normal, interstratified slate (argillite) beds in the Goldenville Formation metasandstones (Sangster, 1990).

Arsenopyrite characterizes all the gold districts in variable amounts up to 5%. It is most abundant in wall rocks, but also occurs within quartz veins (Sangster, 1990).

Gold in Nova Scotia

The first vein-hosted gold discovery in the Meguma Terrane occurred at Mooseland in 1858 by Lieutenant C. L'Estrange while hunting moose (Malcolm, 1929). This led to a major gold rush for Nova Scotia and by the beginning of the Twentieth Century, the Government of Nova Scotia had recognized 60 gold districts throughout the province. Production continued relatively unabated until the beginning of the Second World War in 1939. Since 1939, only limited, sporadic production occurred except from 1983-1987 when a federal exploration incentive, coupled with relatively steady gold prices, allowed for some limited production (Ryan and Smith, 1998).

For historic and descriptive geological details, Malcolm (1929) summarizes the first 70 years of gold exploration and mine development in the Meguma Terrane of Nova Scotia. Bates (1987) summarizes the historic milling methods (i.e. stamp mills, etc.) used to crush the gold ore, and gold extraction methodologies involving the use of shaker tables in combination with amalgamation (the addition of mercury) or cyanidation (crushed ore is dissolved in a mixture of lime and cyanide).

History of the Upper and Lower Seal Harbour Gold Districts

Historical production (1893-1944) from the Upper Seal Harbour gold district totalled 57,027 ounces of gold recovered from quartz veins in the Goldenville Formation (Sangster, 1990). The majority of the production from the district came from the Richardson Belt, first discovered in 1892 by Howard Richardson (Malcolm, 1929). At the hinge of the anticline, quartz veins attained thicknesses of up to 6 m, thinning down the limbs of the fold (Malcolm, 1929). At this gold district, gold is known to occur in three distinct settings: (1) bedding-concordant (or ribbon) quartz veins; (2) irregular *en echelon* quartz veins stratabound within slate units; and (3) disseminated gold within arsenopyrite-rich black slate beds (Ryan and Smith, 1998). The re-furbished (1988) Boston Richardson headframe served as a prominent landmark during the 2004 regional sampling program. Cement and timber foundations at the Boston Richardson mill site, located on the southwest shore of Gold Brook Lake, are the last remaining evidence of the former, grand mill site structure.

Prospecting first occurred in the Lower Seal Harbour Gold District as early as 1868 when glacially dispersed, gold-bearing boulders were found (Malcolm, 1929). A total production of 34,295 ounces of gold was recovered from the district from1894-1942 (Sangster, 1990). Like most significant deposits, the Lower Seal Harbour gold district is located in metasedimentary rocks of the Goldenville Formation.

Similar to the foundations noted at Upper Seal Harbour, deteriorating cement foundations and cement shaft collars characterize the Lower Seal Harbour gold district today, as does a small, free-standing cement building that presumably was used as a vault to store gold. The cement foundation of the former cyanide plant is still relatively well preserved. Both the Upper and Lower Seal Harbour gold districts also showed extensive evidence of exploration and mining as trenches, pits, waste rock piles and tailings characterize both districts.

Surficial Geology

Generally, most of the surficial deposits and associated landforms throughout Nova Scotia were formed during the Wisconsinan glaciation in the last 70,000 years (Lewis *et al.*, 1998). Super-imposed till sheets and various multiple-flow directional indicators have been mapped and document that Nova Scotia is characterized by a complex ice flow history (Stea *et al.*, 1992, Stea and Finck, 2001).

The oldest observed ice flow indicators on land are directed toward the east and southeast and are responsible for the formation of the Hartlen Till associated with the Caledonia Phase (75-40 ka).

South and southwest flow of the Escuminac Phase (22-18 ka) followed and was responsible for deposition of the Lawrencetown Till. The Scotian Phase (18-15 ka) was characterized by an ice divide situated over most of Nova Scotia, and the resulting ice flow varied from northwestward in northern Nova Scotia to south and southeast in southern Nova Scotia followed by formation of the Beaver River Till. The Chignecto Phase (13-12.5 ka) was characterized by shifting ice flow associated with several small ice caps, the remnants of waning stages of the Scotian Phase glacier (Stea and Finck, 2001).

Enrichment of gold and arsenic, with lesser enrichment of copper, lead, zinc, tungsten bismuth, tellurium and iron, characterize the gold deposits of the Meguma Terrane (Kontak and Smith, 1993). These elements are commonly geochemically enriched in soil and till down-ice from known gold occurrences (Coker *et al.*, 1988) resulting from mechanical dispersion (erosion, transportation and deposition) by advancing glacial ice. Glacial dispersal distances vary in Nova Scotia from hundreds of metres to several kilometres down-ice from source (Stea and Fink, 2001).

Methodology

Introduction

During the 2004 field season, 22 regional A-horizon humus, B-horizon soil and C-horizon till samples were collected from the Upper and Lower Seal Harbour gold districts from an area covering approximately 120 km^2 (Fig. 1).

Prior to the humus/soil/till sampling program, a review was undertaken of the local: (1) ice flow history, (2) bedrock stratigraphy, (3) bedrock structure, (4) vein orientation and (5) mining development (including the location of tailings ponds and mill structures for each district). To determine the best location for sample collection, sample sites were carefully chosen to provide: (1) a broad aerial distribution of sample sites, (2) representative coverage of the major surficial units within the study area, (3) representative coverage of the major rock units within the study area and (4) easy access by taking advantage of pre-existing roads.

At each sample site, detailed field descriptions, including observations on till type, colour, texture and clast type and percentage, were recorded. Sample sites were geo-referenced (NAD 27) to the Universal Transverse Mercator (UTM) grid with a GARMIN GPS 12 using the averaging function.

Field Sampling Methodology

A-horizon humus samples were collected by lifting the live, moss-covered forest floor and collecting the underlying black, decaying humus material by hand. Generally, the A-horizon was relatively thin, averaging about 2 cm to 3 cm in thickness. At several sites, however, the depth increased to approximately 10 cm thick. Pebbles and soil attached to the humus were removed and any living plant matter was also selectively removed prior to placement into a Kraft bag. Approximately 250 g of humus were collected from each site.

B-horizon soil samples were also collected at each site from an average sampling depth of 20 cm. Approximately 500 g of soil were collected by shovel and/or auger and placed into Kraft sample bags for future geochemical analysis. Visible organic material and large clasts were selectively removed by hand at each sample site.

The C-horizon till samples were also collected by shovel and/or auger from small hand-dug pits with an average sampling depth of approximately 125 cm (minimum sampling depth was 80 cm). Approximately 500 g of till were collected from each site and placed into Kraft sample bags for future geochemical analysis. Once again, all visible organic material was removed from the sample prior to placement into the Kraft bag. The >1 cm clast fraction was removed (with a plastic sieve) and washed in the field. Estimates of the relative proportions of metasandstone, slate, granite, quartz and "other" clasts were recorded and photographed digitally for future reference. The clasts were then discarded in the field.

In addition to the regional multi-media sampling program, detailed sampling of B-horizon soil was completed within and proximal to the footprint of the former Boston Richardson Mill (Fig. 1) complex site located on the southwestern shore of Gold Brook Lake. Sixteen B-horizon soil samples were collected from an average sampling

Figure 1. Locations of regional humus, soil and till samples. Sample locations are solid circles and shafts are represented by an x. 1 = Goldenville Formation, 2 = Halifax Formation, 3 = granite.

depth of 20 cm to determine the extent of surface enrichment of As and Hg (plus other elements) associated with the milling of ore and the subsequent recovery of gold (utilizing mercury amalgamation). Each sample site represents a composite of a minimum of three sample sites from within a 10 m^2 area. The majority of the sites exhibited some form of visible anthropogenic influence, including the presence of one or more of the following: tailings, cement timber foundations, waste rock piles, rock walls built from waste rock, old bricks, steel pipes, charcoal and proximity to old roads.

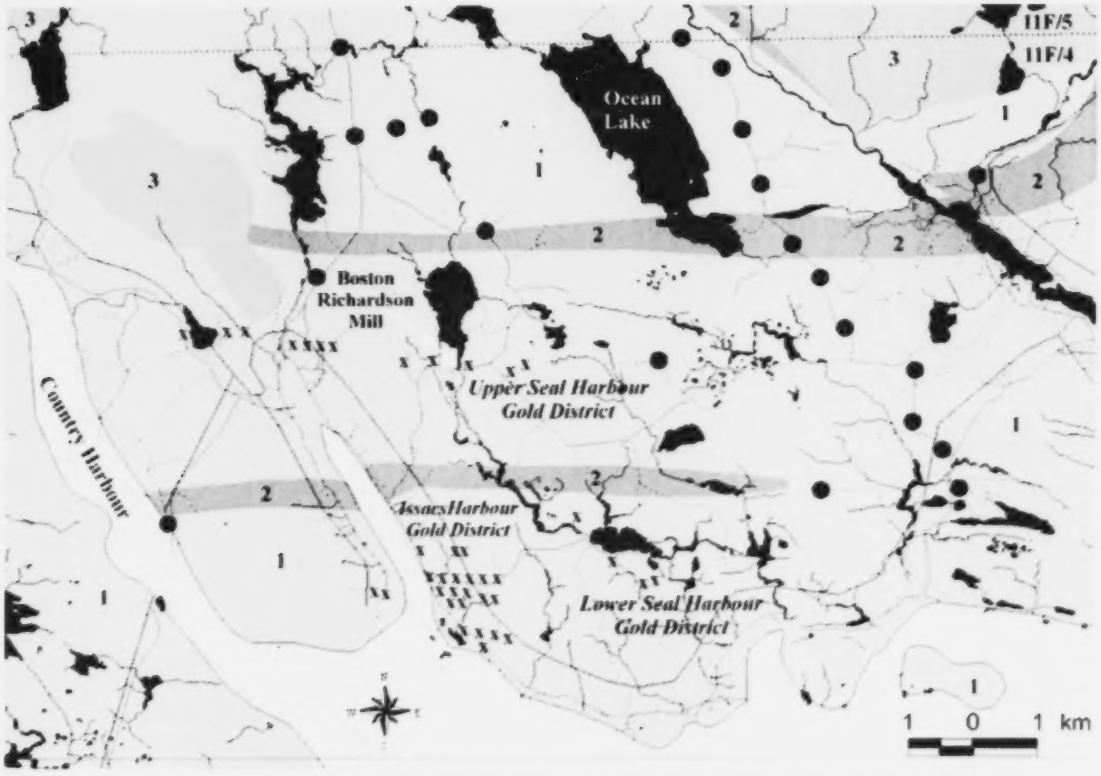
Laboratory Preparation and Analytical Methodology

All humus, soil and till samples were prepared at DalTech Minerals Engineering Centre (Dalhousie University) in Halifax, Nova Scotia. All samples were air dried for several days to a maximum drying temperature of 30 degrees Celsius (°C) to minimize loss of volatile elements such as mercury. Two vials (approximately 15 g to 30 g) of < 2000 µm (< 2 mm) and two vials (approximately 15 g to 30 g) of < 63 µm were prepared for each medium of humus, soil and till.

Prepared humus, soil and till samples were sent to ACME Analytical Laboratories Limited of Vancouver, British Columbia, for a 15 g ICP-MS multi-element analysis following an aqua regia digestion.

Quality Assurance/Quality Control (QA/QC)

Quality assurance quality control (QA QC) measures were incorporated into the sampling



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Laboratory Preparation and Analytical Methodology

All humus, soil and till samples were prepared at DalTech Minerals Engineering Centre (Dalhousie University) in Halifax, Nova Scotia. All samples were air dried for several days to a maximum drying temperature of 30 degrees Celsius (°C) to minimize loss of volatile elements such as mercury. Two vials (approximately 15 g to 30 g) of <2000 µm (<2 mm) and two vials (approximately 15 g to 30 g) of <63 µm were prepared for each medium of humus, soil and till.

Prepared humus, soil and till samples were sent to ACME Analytical Laboratories Limited of Vancouver, British Columbia, for a 15 g ICP-MS multi-element analysis following an aqua regia digestion.

Quality Assurance/Quality Control (QA/QC)

Quality assurance/quality control (QA/QC) measures were incorporated into the sampling

program and the preparation and analytical procedures to ensure the highest confidence in the quality of the data.

In the field, personnel were trained with respect to standard sampling procedures and the acquisition of necessary site description information. One field duplicate was collected from the regional geochemical program to test for natural site variance. (No field duplicates were collected during the detailed soil sampling program associated with the former Boston Richardson Mill site because of the overwhelming evidence of contamination).

Each sample site was photographed with a digital camera for future reference. For the detailed soil sampling program associated with the former Boston Richardson Mill site, however, only representative pictures of the overall mill site were taken.

Due to the lack of an available humus reference standard, CANMET (Canadian Certified Reference Materials Project – CCRMP) lake sediment standard LKSD-4 was inserted as a reference control material because of its high organic content. A laboratory prepared preparation split was also inserted with these humus samples.

CANMET till standard TILL-1 and an in-house reference standard (informally referred to as STEA-1) were inserted with all regional soil and till batches. A laboratory prepared preparation split was also inserted with both the soil and till samples.

Results

Analytical results are pending for all samples.

Discussion

Overall, the clast and matrix composition of the till strongly reflects the underlying bedrock lithology, indicating that the till is locally derived. The local nature of the till is further demonstrated by the angularity of the clasts, the presence of large boulders, and the compact nature of the till. Till samples collected within the study area were dominated by metasandstone facies of the Beaver River Till.

Locally, on the extreme eastern end of the study area, a slate facies till (SH04 SC08) associated with the Halifax Formation slate was encountered. The area was further characterized by relatively abundant slate outcrop. It should be noted that there was less clay in the matrix than anticipated for slate facies till, and there were numerous sub-rounded to rounded clasts suggesting there may be some degree of fluvial reworking considering the proximity to the New Harbour River. Clear evidence (sorted beds, rounded clasts etc.) of fluvial re-working and deposition was noticed at lower elevations (near the New Harbour River).

An increase in the number of granite clasts and the presence of a slightly coarser sand matrix was noted in several of the till samples collected from the northeastern part of the study area. Granite plutons, represented as local topographic highs, are known to exist immediately north of the study area.

All regional humus, soil and till samples collected in the field were deemed to be of excellent quality and not influenced by any anthropogenic effects (i.e. tailings, waste rock piles, garbage, etc.). Conversely, almost all of the 16 soil samples collected within and near the footprint of the Boston Richardson Mill complex showed visible anthropogenic effects.

The regional sample sites, in general, were biased north of the Upper and Lower Seal Harbour anticlines (and east of the main workings) in order to minimize the (cumulative) affect of glacial erosion, transportation and deposition of mineralized bedrock material associated with the gold districts. However, any effects of glacial erosion, transportation and deposition of mineralized bedrock material associated with known gold mineralization farther up-ice (i. e. Forest Hills) could not be ruled out.

Conclusions

During the 2004 field season, sample sites were visited and geochemical samples were collected as part of a regional sampling program at the Upper and Lower Seal Harbour gold districts. At each site, an A-horizon humus, B-horizon soil and C-horizon till sample were collected. The <63 µm and

<2000 μm (<2 mm) fractions for all humus, soil and till samples were prepared at DalTech Minerals Engineering Centre (Dalhousie University) in Halifax, Nova Scotia. These prepared humus, soil and till samples were subsequently sent to ACME Analytical Laboratories Limited of Vancouver, British Columbia, for a 15 g ICP-MS multi-element analysis following an aqua regia digestion. Quality assurance/quality control (QA/QC) measures were incorporated into all stages of the sampling program to ensure the highest confidence in the quality of the data.

In addition to the regional multi-media sampling program, detailed sampling of B-horizon soil was completed within and near the footprint of the former Boston Richardson Mill site located on the southwestern shore of Gold Brook Lake. Sixteen composite B-horizon soil samples were collected from an average sampling depth of 20 cm. The detailed B-horizon soil samples were prepared in an identical manner as the regional B-horizon soil samples using the same QA/QC protocols.

The Upper and Lower Seal Harbour sampling program is part of a 3-year multi-disciplinary project, initiated in the spring of 2003 as part of the Geological Survey of Canada's Metals in the Environment (MITE) Program. The main objective of the MITE program is to examine the distribution of metals in the environment associated with past-producing gold districts throughout the province by characterizing regional and local background concentrations and speciation of the elements. This study will assist the understanding and quantification of off-site transport of various elements from mine waste (tailings and waste rock dumps), and the transformation and fate of these elements in receiving environments (e.g. streams, lakes, etc.).

Analytical results are pending for all samples.

References

Bates, J. L. E. 1987: Gold in Nova Scotia; Nova Scotia Department of Mines and Energy, Information Series No. 13, 48 p.

Coker, W. B., Sexton, A., Lawyer, I. and Duncan, D. 1988: Bedrock, till and soil geochemical signatures at the Beaver Dam gold deposit, Nova Scotia, Canada; *in* Prospecting in Areas of Glaciated Terrain - 1988, eds. D. R. MacDonald, K. A. Mills and Y. Brown; The Canadian Institute of Mining and Metallurgy, Eight International Symposium on Prospecting in Areas of Glaciated Terrain, p. 241-255.

Eaton, P. 1978: Investigation of mercury-related environmental effects associated with abandoned amalgamation operations in Nova Scotia; Montreal Engineering Company, Limited for Environmental Protection Service (Atlantic Region), Fisheries and Environment Canada, 37 p.

Goodwin, T. A., Smith, P. K. and Parsons, M. P. 2003: Multi-element distribution in humus, soil, till, rock and tailings associated with historical gold districts of the Meguma Zone, Nova Scotia, Canada; *in* Mineral Resources Branch, Report of Activities 2003; Nova Scotia Department of Natural Resources, Report 2004-1, p. 7-14.

Kontak, D. J. and Smith, P. K. 1993: A metaturbidite-hosted lode gold deposit: the Beaver Dam deposit, Nova Scotia. I. vein paragenesis and mineral chemistry; Canadian Mineralogist, v. 31, p. 471-522.

Lewis, C. F. M., Taylor, B. B., Stea, R. R., Fader, G. B. J., Horne, R. J., MacNeill, S. G. and Moore, J. G. 1998: Earth science and engineering: urban development in the Metropolitan Halifax Region; *in* Urban Geology of Canadian Cities, eds. P. F. Karrow and O. L. White; Geological Association of Canada, Special Paper 42, p. 409-444.

MacDonald, M. A. and Horne, R. J. 1987: Geological map of Halifax and Sambro; Nova Scotia Department of Mines and Energy, Map 87-6, scale 1:50 000.

Malcolm, W. 1929: Gold Fields of Nova Scotia; Geological Survey of Canada, Memoir 156, 253 p.

O'Brien, B. H. 1983: The structure of the Meguma Group between Gegogan Harbour and Country Harbour, Guysborough County; *in* Mines and Minerals Branch, Report of Activities 1982, ed. K. A. Mills; Nova Scotia Department of Mines and Energy, Report 83-1, p. 145-181.

Ryan, R. J. and Smith, P. K. 1998: A review of mesothermal gold deposits of the Meguma Group, Nova Scotia, Canada; *in* Ore Geology Reviews, eds. W. R. H. Ramsay, F. P. Bierlein

and D. C. Arne; v. 13, nos. 1-5, p. 153-183.

Sangster, A. L. 1990: Metallogeny of the Meguma Terrane, Nova Scotia; *in* Mineral Deposit Studies in Nova Scotia, Volume 1, ed. A. L. Sangster; Geological Survey of Canada, Paper 90-8, p. 115-162.

Smith, P. K. 1983: Geology of the Cochrane Hill Gold Deposit, Guysborough County, Nova Scotia; *in* Mines and Minerals Branch, Report of Activities 1982, ed. K. A. Mills; Nova Scotia Department of Mines and Energy, Report 83-1, p. 225-256.

Smith, P. K. and Kontak, D. J. 1988: Meguma gold studies II: vein morphology, classification and information, a new interpretation of 'crack-seal' quartz veins; *in* Mines and Minerals Branch, Report of Activities 1987, Part B, eds. D. R. MacDonald and Y. Brown; Nova Scotia Department of Mines and Energy, Report 88-1, p. 61-76.

Stea, R. R., Conley, H. and Brown, Y. (compilers) 1992: Surficial geology of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Map 92-3, scale 1:500 000.

Stea, R. R. and Finck, P. W. 2001: An evolutionary model of glacial dispersal and till genesis in Maritime Canada; *in* Drift Exploration in Glaciated Terrain, eds. M. B. McClenaghan, P. T. Bobrowsky, G. . Hall S. J. Cook; Geological Society of London Special Publication No. 185, p. 237-265.

Multi-element Geochemical Response of Humus, Soil and Till Across the Cobequid-Chedabucto Fault Zone, Northern Nova Scotia[1]

T. A. Goodwin

Introduction

The Targeted Geoscience Initiative (TGI) is a federal-provincial program designed to assist and promote mineral and energy exploration. The Nova Scotia component of the current TGI program has focused on map areas covering the Cobequid-Chedabucto Fault Zone (CCFZ) (11E/06, 11E/07, 11E/08 and parts of 11E/05 and 11E/12). Field work was undertaken in the summer of 2004 to collect regional A-horizon humus, B-horizon soil and C-horizon till samples in order to characterize the geochemical response from each sample medium, particularly where it is associated with the CCFZ.

The majority of the study area is underlain by Carboniferous strata that are of considerable interest for hydrocarbon and mineral resource potential. Uncertainty about the stratigraphy, structure and regional geochemistry of humus, soil, and to a lesser extent till of the study area, particularly near known and inferred structures, has often hindered exploration efforts.

Currently, there is a strong mineral exploration interest for iron oxide-copper-gold (IOCG) mineralization proximal to the Cobequid-Chedabucto Fault Zone. Unfortunately, regional geochemical sampling of humus, soil and till specific to IOCG mineralization does not exist in the study area. Humus and soil have never been collected during any regional provincial geochemical survey, although limited humus and soil data are available in the public domain assessment reports. Regional NSDNR till geochemical data of various vintages are available, as are stream sediment/water data, but not all elements of current interest were initially analyzed by the department.

Similarly, there is increased exploration interest for assessing the on-shore oil and gas potential, paralleling major offshore oil and gas exploration, as current world oil and natural gas prices continue to rise under pressures from increasing demand, limited supplies and uncertainty of the security of supply.

Bedrock Geology

Southern mainland Nova Scotia lies within the Meguma Terrane, which is dominated by the Meguma Group, a 9000 m thick succession of Cambro-Ordovician siliciclastics that hosts most of Nova Scotia's gold deposits, and younger intrusive granites (Ryan and Smith, 1998). The Meguma Terrane docked with the eastern side of the Avalon Platform during the Middle Devonian Acadian Orogeny (Keppie, 1982, 1985). The boundary between the Avalon Terrane to the north and the Meguma Terrane to the south is commonly referred to as the Cobequid-Chedabucto Fault Zone. The CCFZ is characterized by numerous faults, locally intense deformation (ductile to brittle), and associated regional-scale alteration (i.e. carbonate, hematite). The east-west St. Mary's Basin further characterizes the CCFZ. The basin, bounded to the south by the West River St. Mary's Fault and to the north by the Chedabucto Fault, is composed of Carboniferous siliciclastic sediments of the Horton Group (Benson, 1974).

The Avalon Terrane is dominated by Carboniferous basin-fill sedimentary strata and two large fault blocks of Precambrian to lower Paleozoic crystalline basement rocks.

The Meguma Terrane is characterized by a distinct pre-Middle Devonian geological history.

[1]Funded by Natural Resources Canada and the Nova Scotia Department of Natural Resources under the Targeted Geoscience Initiative Project (Phase 2): Geological Mapping and Resource Evaluation in Central Nova Scotia

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whereas its post-Middle Devonian geological history is shared with the remainder of Nova Scotia (Sangster, 1990). Intense dextral shearing has significantly modified earlier wall-rock and vein geometries, and characterizes the Meguma Terane south of the CCFZ (Smith, 1984a, b).

For additional information on bedrock and structural geology, refer to O'Reilly (this volume, p. 73-92).

Surficial Geology

Nova Scotia is characterized by a relatively complex ice flow history which includes superimposed till sheets and various multiple-flow directional indicators (Stea *et al.*, 1992; Stea and Finck, 2001). Most of the surficial deposits and associated landforms throughout the province were formed during the Wisconsinan glaciation in the last 70 000 years (Lewis *et al.*, 1998).

The oldest observed ice flow indicators on land show a flow toward the east and southeast, associated with the Caledonia Phase (75-40 ka) from which deposition of the Hartlen Till ensued. This was followed by south and southwest flow of the Escuminac Phase (22-18 ka), responsible for deposition of the Lawrencetown Till. The Scotian Phase (18-15 ka) was characterized by an ice divide over most of Nova Scotia. The resulting ice flow varied from northwestward in northern Nova Scotia to south and southeast in southern Nova Scotia, followed by the formation of the Beaver River Till. The Chignecto Phase (13-12.5 ka) was characterized by shifting ice flow associated with several small ice caps, the remnants of waning stages of the Scotian Phase glacier (Stea and Finck, 2001).

Glacial dispersal distances for locally derived till vary in Nova Scotia from hundreds of metres to several kilometres down-ice from source (Stea and Fink, 2001). Conversely, distally derived till, characterized by allochthonous clasts, distinctive texture and colour, are derived from bedrock sources >50 km up-ice (Finck and Stea, 1995).

Methodology

Introduction

During the 2004 field season, 59 regional A-horizon humus samples, 59 B-horizon soil samples, and 59 C-horizon till samples were collected from north-south transects across NTS map areas 11E/06, 11E/07, 11E/08 and parts of 11E/05 and 11E/12 (Fig. 1).

Prior to this sampling program, a review of the regional (1) ice flow history, (2) surficial geology, (3) bedrock geology and (4) bedrock structure was undertaken. Sample sites were carefully chosen to provide (1) representative north-south profiles, (2) representative coverage of the major surficial units within the study area, (3) representative coverage of the major rock units in the study area, (4) coverage proximal to and across known (and inferred) structures and (5) easy access by taking advantage of pre-existing roads.

At each sample site, detailed field descriptions, including observations on sample depth, sample type, sample colour, sample texture and clast type and percentage, were recorded. All sample sites were geo-referenced (NAD 27) to the Universal Transverse Mercator (UTM) grid with a GARMIN GPS 12 using the averaging function. Each sample site was photographed with a digital camera for future reference.

Field Sampling Methodology

A-horizon humus samples were collected by pulling off the live, moss-covered forest floor and collecting the black, decaying humus material by hand. Generally, the A-horizon was relatively thin, averaging about 2 cm to 3 cm in thickness and rarely exceeding 5 cm thick. Pebbles and mineral soil attached to the humus were removed by shaking the sample, and any living plant matter was also selectively removed. Approximately 250 g of humus were collected from each site and placed into a Kraft bag.

B-horizon soil samples were also collected at each site and were collected from an average sampling depth of about 20 cm. Approximately 500 g of B-horizon soil were collected by shovel and/or auger and placed into Kraft sample bags for future geochemical analysis. Decaying and living organic material, as well as large clasts, were selectively removed by hand prior to placing the sample in the bag.

C-horizon till samples were also collected by shovel and/or auger from small hand-dug pits with

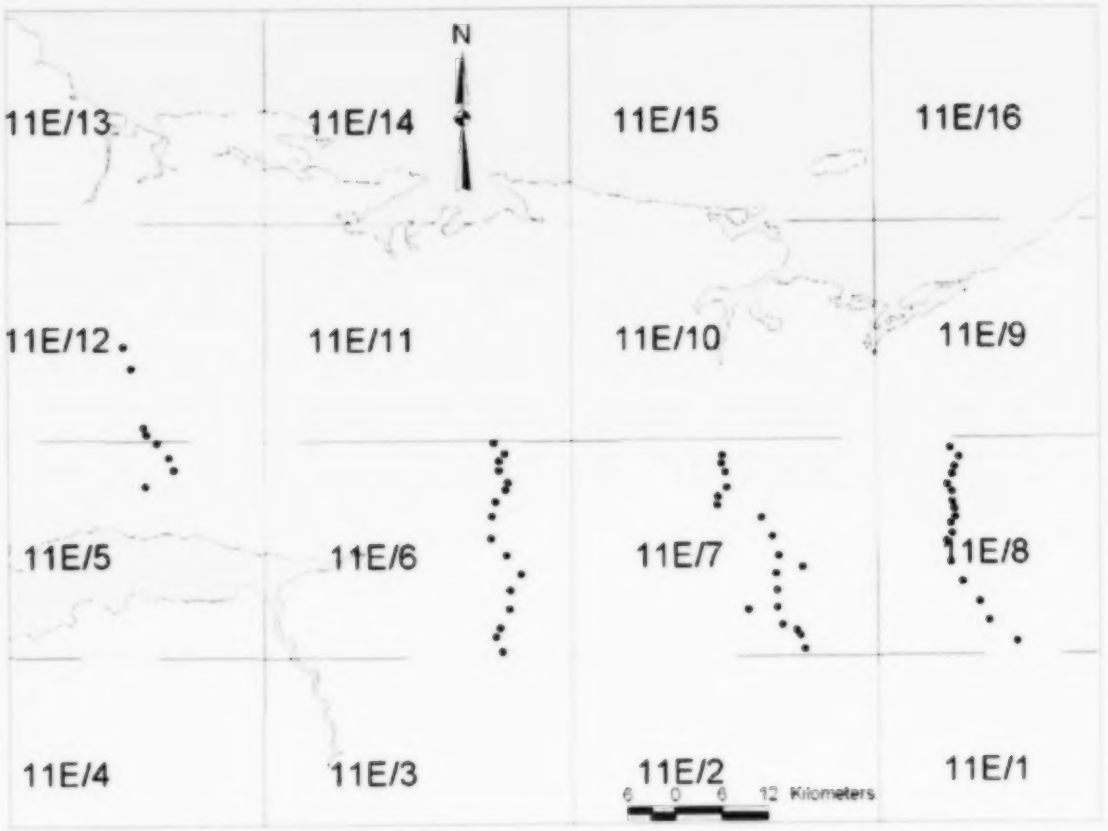

Figure 1. Regional humus, soil and till sample location map. Sample sites are represented by a solid circle.

an average sampling depth of approximately 125 cm (minimum sampling depth was 70 cm). Approximately 500 g of till were collected from each site and placed into Kraft sample bags. Once again, all organic material as well as large clasts were removed from the sample prior to placement into the Kraft bag.

Laboratory Preparation and Analytical Methodology

Humus, soil and till samples were prepared at DalTech Minerals Engineering Centre (Dalhousie University) in Halifax, Nova Scotia. The samples were air dried for several days to a maximum drying temperature of 30 degrees Celsius (°C) in order to minimize loss of volatile elements such as mercury. Two vials (approximately 15 g to 30 g) of <2000 µm and two vials (approximately 15 g to 30 g) of <63 µm were prepared for each medium of humus, soil and till.

The prepared humus, soil and till samples were sent to ACME Analytical Laboratories Limited of Vancouver, British Columbia. A 5 g humus sub-sample was analyzed for multi-element analysis by ICP-MS following an aqua regia digestion (package 1VE-MS Full Suite+Pt+Pd). 15 g soil and 15 g till sub-samples were also analyzed for multi-element analysis by ICP-MS following an aqua regia digestion (package 1F-MS Full Suite+Pt+Pd).

Quality Assurance/Quality Control (QA/QC)

Quality assurance/quality control (QA/QC) measures were incorporated into all stages of the sampling program and the preparation and analytical procedures to ensure the highest confidence in the quality of the data.

Field personnel were trained with respect to standard sampling procedures and the acquisition of necessary site description information. Digital photographs of all the regional geochemical sampling sites were taken for future reference and archiving.

Field duplicates, preparation splits and reference standards were inserted into the sampling protocol to test for natural site variance as well as the accuracy and precision of the analytical methodology. Reference standard TILL-3 (Canadian Certified Reference Materials Project – CCRMP) and the in-house reference standard STEA-1 were inserted with all regional B-horizon soil samples. Similarly, reference standard TILL-2 (CCRMP) and the in-house reference standard STEA-1 were inserted with all regional C-horizon till samples. Due to the lack of available humus reference standard, organic-rich CCRMP lake sediment standard LKSD-4 was inserted as a reference control material.

Results

Analytical results are pending for all samples.

References

Benson, D. G. 1974: Geology of the Antigonish Highlands, Nova Scotia; Geological Survey of Canada, Memoir 376, 92 p.

Finck, P. W. and Stea, R. R. 1995: The compositional development of tills overlying the South Mountain Batholith; Nova Scotia Department of Natural Resources, Mines and Minerals Branch, Paper 95-1, 51 p.

Keppie, J. D. 1982: Major structural zones and faults of the Northen Appalachians, edited by P. St.-Julien and J. Beland; Geological Association of Canada, Special Paper 24, p. 263-280.

Keppie, J. D. 1985: Geology and tectonics of Nova Scotia; *in* Excursion 1 – Appalachian Geotraverse, eds. J. D. Keppie, K. L. Currie, J. B. Murphy, R. K. Pickerill, L. R. Fyffe and P. St. Julian; Geological Association of Canada/Mineralogical Association of Canada, Fredericton, v. 85, p. 181.

Lewis, C. F. M., Taylor, B. B., Stea, R. R., Fader, G. B. J., Horne, R. J., MacNeill, S. G. and Moore., J. G. 1998: Earth science and engineering: urban development in the Metropolitan Halifax region; *in* Urban Geology of Canadian Cities, eds. P. F. Karrow and O. L. White; Geological Association of Canada, Special Paper 42, p. 409-444.

Ryan, R. J. and Smith, P. K. 1998: A review of mesothermal gold deposits of the Meguma Group, Nova Scotia, Canada; *in* Ore Geology Reviews, eds. W. R. H. Ramsay, F. P. Bierlein and D. C. Arne; v. 13, Nos. 1-5, p. 153-183.

Sangster, A. L. 1990: Metallogeny of the Meguma Terrane, Nova Scotia; *in* Mineral Deposit Studies in Nova Scotia, Volume 1, ed. A. L. Sangster; Geological Survey of Canada, Paper 90-8, p. 115-162.

Smith, P. K. 1984a: Geology and lithogeochemistry of the Cochrane Hill gold deposit – an indication of metalliferous source beds; Nova Scotia Department of Mines and Energy, Report 84-1, p. 203-214.

Smith, P. K. 1984b: Geological map of the Cochrane Hill open-pit gold deposit; Nova Scotia Department of Mines and Energy, Map 84-1.

Stea, R. R., Conley, H. and Brown, Y. (compilers) 1992: Surficial geology of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Map 92-3, scale 1:500 000.

Stea, R. R. and Finck, P. W. 2001: An evolutionary model of glacial dispersal and till genesis in Maritime Canada; *in* Drift Exploration in Glaciated Terrain, eds. M. B. McClenaghan, P. T. Bobrowsky, G. E. Hall and S. J. Cook; Geological Society of London, Special Publication No. 185, p. 237-265.

The Hillsvale Vein System, Hants County

R. J. Horne, R. R. Stea and D. J. Kontak

Introduction

A number of previously undocumented, bedding-parallel quartz veins were discovered in the Hillsvale area (Figs. 1, 2) during regional bedrock mapping in the summer of 2004. At least 30 veins are exposed along a recently established logging road developed on the west side of the paved road between Lakelands and Hillsvale (Hillsvale Road, Fig. 3), NTS map area 11D/13 and 11E/04. The character of these veins is similar with respect to vein type, setting, density and mineralogy to veins that constitute the many Meguma Group gold districts, and therefore present a potential exploration target. Although the veins are locally well exposed as a result of road construction, there is no evidence that these veins had been previously sampled or otherwise evaluated. A few 'leads' are indicated along strike to the southwest of these veins (Fig. 3) and to the northeast on Meander River (Fig. 2) on the geological map of the area by Fletcher and Faribault (1909). In addition to the road exposures, a few quartz veins and some quartz float were also found in the area south of where the veins are exposed on the road (Fig. 3).

Setting

The Hillsvale vein array occurs on the steep to slightly overturned north limb of the Rawdon Gold Mines Anticline (Figs. 2, 3). The Rawdon Gold Mines Anticline represents the north end of the Mount Uniacke anticlinorium, which is bound in the south by the steep-dipping south limb of the Mount Uniacke Anticline. The Mount Uniacke anticlinorium defines a kilometre-scale box fold with open folds between the steep limbs (Fig. 2). The vein array at Hillsvale is hosted by the Goldenville Formation, consisting primarily of metasandstone with minor metasiltstone and slate.

Veins

Thirty bedding-parallel quartz veins are exposed along two intervals of the new logging road (veined intervals, Fig. 3). There is incomplete exposure in both intervals, as well as between them, and it is likely that additional veins occur. All veins occur in metasiltstone or slate intervals, commonly at the contact with metasandstone beds. The spacing of bedding-parallel veins is highly anomalous with respect to regional vein concentrations, and comparable only to vein concentrations within Meguma gold districts.

Veins range from 1 cm to 30 cm in thickness, and most consist primarily of massive quartz (Fig. 4). Locally, some of the veins have a coarsely laminated texture and some are boudinaged. Sulphide minerals are not abundant, but arsenopyrite was noted in a few veins as well as in the adjacent wall rock.

Veins 1 through 21 were sampled, inspected and analyzed for gold, arsenic, copper, lead and zinc at the Minerals Engineering Centre, Dalhousie University (Table 1). Samples represent "grab samples" collected from surface exposures of limited extent and are intended as a first evaluation of the veins. Results of the geochemical analysis (Table 1) indicate gold levels ranging from less than detection (<0.003 ppm) up to 0.03 ppm. Several samples returned elevated arsenic levels, ranging up to 8670 ppm, consistent with observed arsenopyrite in some veins and wall rock. Base metal (Cu, Pb, Zn) levels are generally low, although elevated in some samples. The gold concentrations, although generally low, are similar to levels found in the non-economic parts of vein systems in Meguma lode gold deposits (P. K. Smith, personal communication), and therefore do not preclude the possibility of elevated, economic levels elsewhere within the vein system. The elevated arsenic and locally elevated base metal concentrations are consistent with auriferous veins of Meguma gold districts, where gold and base metal levels are typically erratic, but locally elevated.

Till Sampling

Six till samples were collected over an area

Horne, R. J., Stea, R. R. and Kontak, D. J. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 39-44

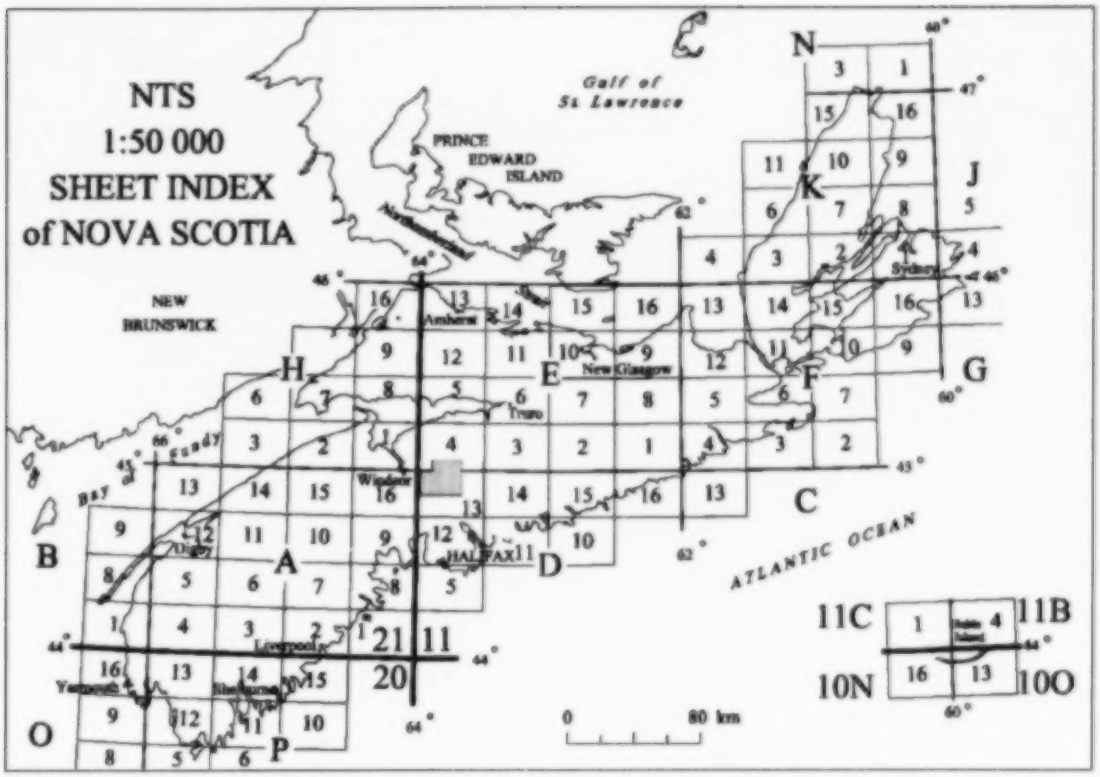

Figure 1. NTS Index map of Nova Scotia showing the location of Figure 2 covering parts of NTS sheets 11D/13 and 11E/04

extending north and south of the exposed veins in an attempt to assess the potential gold content of the veins (Fig. 3). Till in the area is thin to non-existent and its origin is uncertain. Locally, exposed striations indicate an episode of northward ice flow. Mineral concentrations from the till samples produced by a 'Super-Panner' at the Minerals Engineering Centre, Dalhousie University, did not yield any gold grains. The till samples, however, contained very little quartz vein material and the till may not have been derived from local bedrock.

Discussion

The Hillsvale vein array represents an anomalous concentration of bedding-concordant veins in the Meguma Group, and resembles vein arrays constituting the many Meguma gold districts. Discovery of this vein array, therefore, indicates the potential for discovery of new Meguma lode gold deposits. Although no visible gold was observed and gold concentrations are only slightly anomalous at best, we note that only limited exposure of the veins is presented. The low gold levels are not inconsistent with many parts of vein arrays in Meguma gold districts, where significant gold distribution is typically restricted to certain zones (ore shoots). Elevated levels of As, Cu, Pb and Zn are consistent with vein arrays of Meguma gold districts and we suggest that further evaluation is required to establish the gold potential of the Hillsvale vein array.

The Hillsvale vein array is located on the steep limb of the Rawdon Mines Anticline, which defines the north limb of the Mount Uniacke Anticlinorium. It is notable that other gold districts within the Mount Uniacke Anticlinorium occur in similar structural positions: (1) the Rawdon Gold Mines occurs on the north limb of the Rawdon

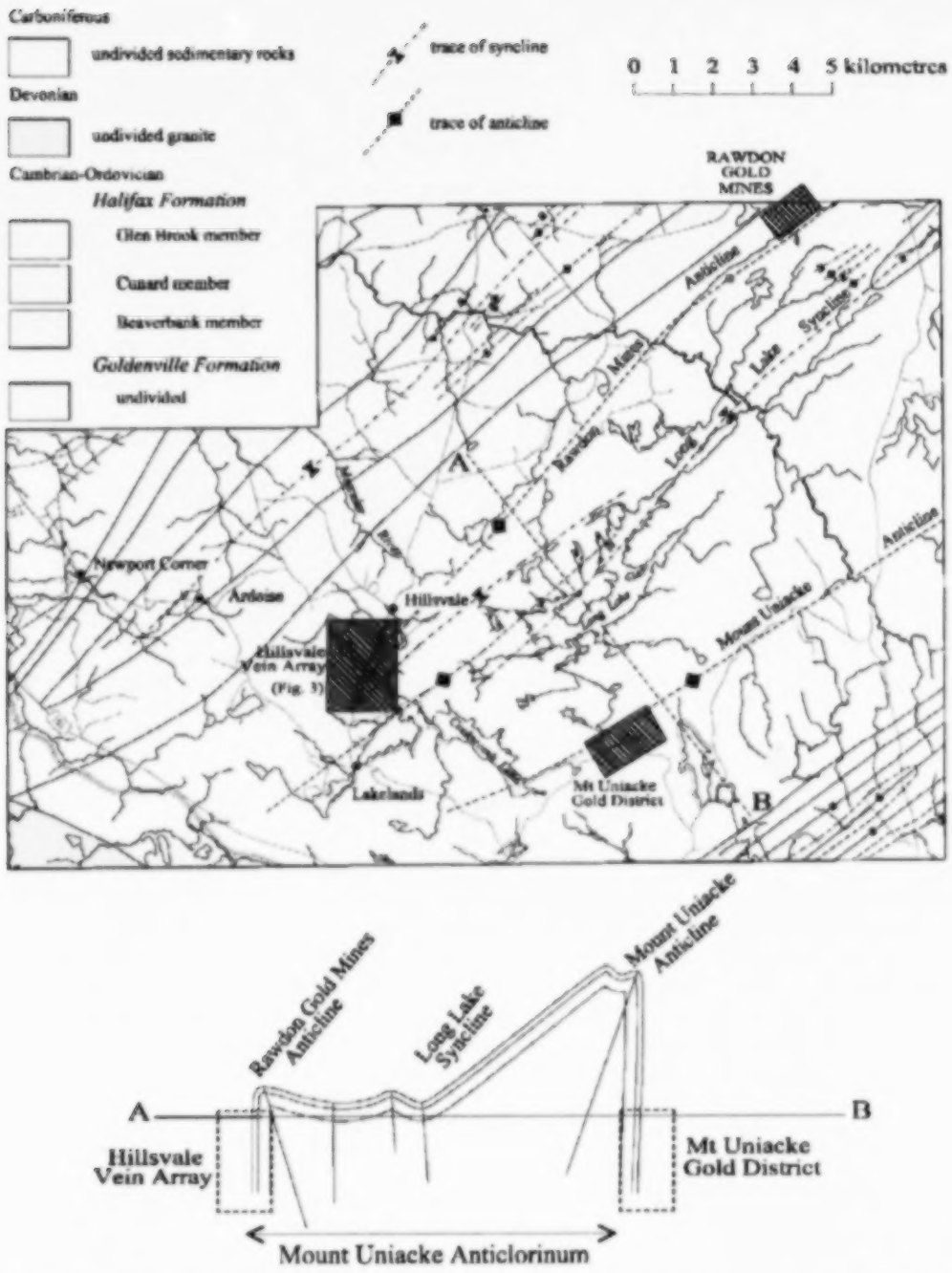

Figure 2. Geological map of the Mount Uniacke-Hillsvale area showing the location of the Hillsvale vein array and the Mount Uniacke and Rawdon Gold Mines gold distncts. Cross section A-B shows the character of the Mount Uniacke Anticlinorium and the locations of the Mount Uniacke gold district and the Hillsvale vein array on the steep limbs of the anticlinorium.

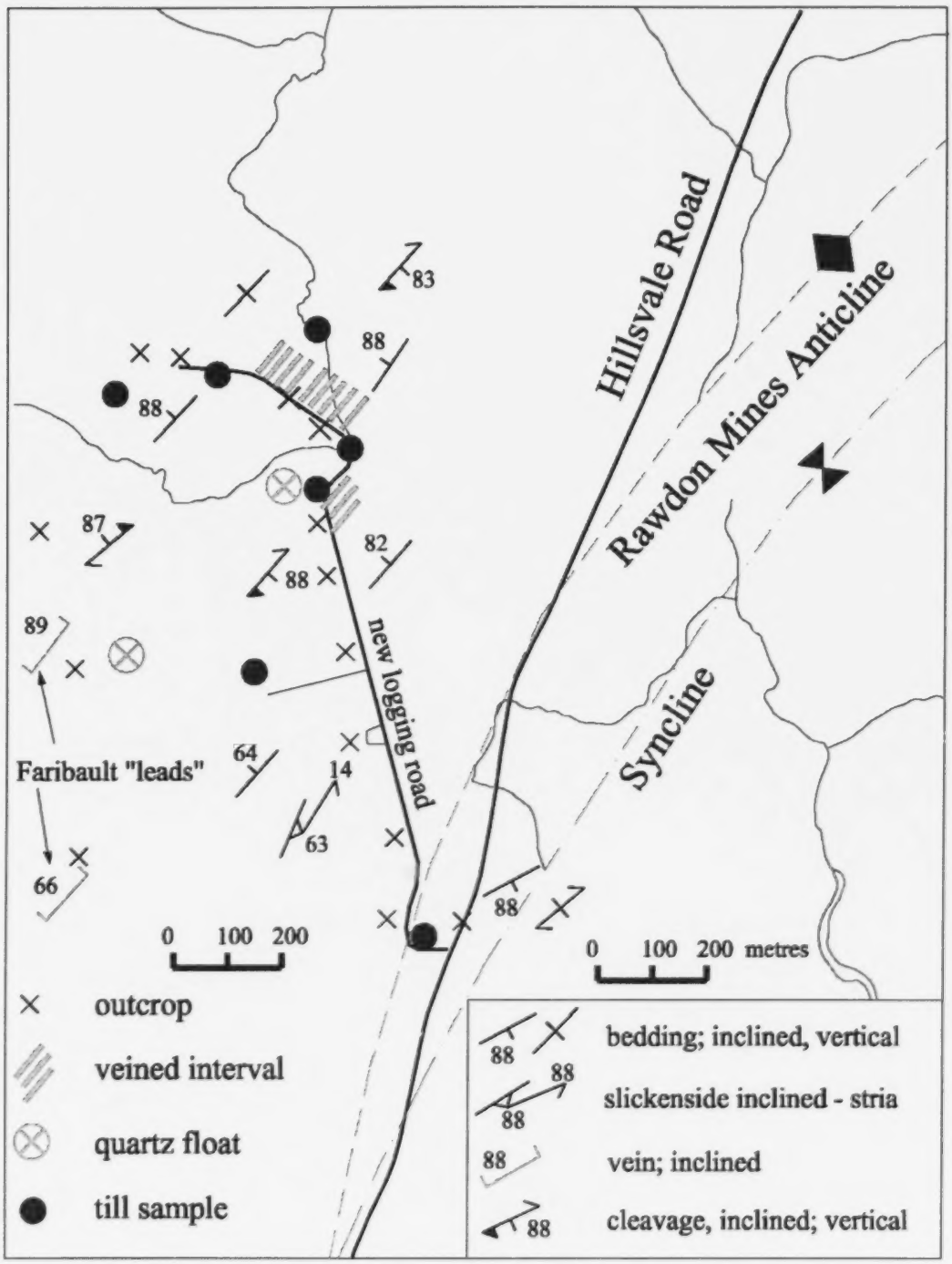

Figure 3. Detailed map showing the location of the Hillsvale vein array (veined interval) exposed on a logging road on the west side of the Hillsvale Road. Area of this map indicated on Figure 2.

Figure 4. Photographs of a bedding-parallel quartz vein in the Hillsvale vein array exposed along logging road off the Hillsvale Road (veined interval, Fig. 3).

Table 1. Table of assay results for selected elements for 21 quartz veins from the Hillsvale vein system. All concentrations given in ppm.

Sample	Au	As	Cu	Pb	Zn
Vein-1	0.005	375	7.0	45.0	53.0
Vein-3	0.003	344	3.1	22.0	4.8
Vein 4	0.003	442	5.9	11.9	5.6
Vein 5	<0.003	254	4.4	17.0	4.7
Vein-6	0.016	8670	3.2	60.0	2.9
Vein-7	0.013	4770	3.3	2.4	1.6
Vein-8	<0.003	58	4.9	5.5	1.4
Vein-9	0.013	130	6.9	10.8	8.0
Vein-10	<0.003	33	11.0	27.0	8.9
Vein-11	<0.003	461	5.1	1.8	2.7
Vein-12	<0.003	87	4.5	2.6	2.5
Vein-13	<0.003	204	4.3	1.3	2.3
Vein-14	<0.003	7650	2.8	30.0	2.6
Vein-15	<0.003	154	4.0	3.3	3.4
Vein-16	0.003	34	40.0	41.0	32.0
Vein-17	<0.003	1630	5.5	10.5	4.7
Vein-18	<0.003	4	7.2	5.4	2.4
Vein-19	<0.003	3460	7.0	298.0	14.7
Vein-20	0.003	226	4.0	0.4	3.2
Vein-21	0.030	273	8.2	1.9	5.6

Gold Mines anticline, along strike of the Hillsvale vein array (Fig. 2); (2) the Mount Uniacke Gold District occurs on the south limb of the Mount Uniacke Anticline (Fig. 2), and (3) the Renfrew Gold District occurs on the south limb of the Renfrew Anticline, which defines the south limb of the Mount Uniacke anticlinorium in that area. The distribution of Meguma gold districts on the step limbs of anticlinoria is not restricted to the Mount Uniacke anticlinorium. For example, the Waverley and Montague districts occur on the north and south limbs of the Waverley anticlinorium (Horne *et al.*, 1998). The distribution of vein arrays on steep limbs is consistent with a model of vein development in response to high flexural-shear strain experienced at high limb dips, where veins form in structures related to bedding-parallel shear (Faribault, 1899; 1913; Horne and Culshaw, 2001; Horne and Jodrey, 2002; Horne *et al.*, 2004). Such a model provides a target for exploration for undiscovered vein arrays, notably along the north limb of the Rawdon Mines Anticline between the Hillsvale vein array and the Rawdon Gold Mines (Fig. 2).

References

Faribault, E. R. 1899: On the gold measures of Nova Scotia and deep mining; The Canadian Mining Review v. 18, no. 3, p. 78-82.

Faribault, E. R. 1913: The gold deposits of Nova Scotia; The Canadian Mining Journal, v. 34, no. 22, p. 108-109 and no. 24, p. 780-781.

Fletcher, H. and Faribault, E. R. 1909: Windsor Sheet, Hants County; Canada Department of Mines.

Horne, R. J., Baker, D, Feetham, M. and MacDonald, L. 1997: Preliminary geology of the Waverly-Halifax airport area, central Nova Scotia: some insights on the timing of deformation and vein formation in the Meguma Group; *in* Mines and Mineral Branch, Report of Activities 1996, eds. D. R. MacDonald and K. A. Mills; Nova Scotia Department of Natural Resources, Report 97-1, p. 57-72.

Horne, R. J., Covey, G. and Albert, C. 2004: Geological report on the early stages of development of the Mooseland Gold District (NTS 11D/15), Halifax County; *in* Mineral Resources Branch, Report of Activities 2003; Nova Scotia Department of Natural Resources, Report 2004-1, p. 25-39.

Horne, R. J. and Culshaw, N. 2001: Flexural-slip folding in the Meguma Group, Nova Scotia Canada; Journal of Structural Geology, v. 23, p. 1631-1652.

Horne, R. J. and Jodrey, M. 2001: Geology of the Dufferin Gold Deposit (NTS 11D/16), Halifax County; *in* Mineral and Energy Branch Report of Activities 2001, ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report ME 2002-1, p. 51-67.

Geoscience Editing and Publishing

D. R. MacDonald, B. L. MacDonald, K. A. Mills and J. S. Saunders

Publications are often the first point of contact between the Mineral Resources Branch and its many and various clients. All geoscientists in the branch are required to publish accounts of their work. These accounts may be published as scientific reports, memoirs or maps, or they may be more effectively summarized in less technical publications such as information circulars or newsletters. All forms of publication play an important role in delivering geoscience information for the branch to enhance public awareness and promote the mineral resources of Nova Scotia.

Staff of the geoscience editing and publishing group work toward the goal of consistent high-quality, timely and cost-effective reporting on activities carried out by the Mineral Resources Branch. The group's work involves editing manuscript maps and reports to the author's satisfaction, while also applying the branch standards for peer review, content and style. The branch follows editorial standards described in the Geological Survey of Canada's *Guide to Authors*. When a map or report has been completed and approved for publication, the group works to prepare the publication for release in hard copy and on line. The Mineral Resources Branch web site contains the largest collection of digital information available from the Government of Nova Scotia, providing an average of 4000 downloads per month, all free of charge.

The following publications were released in 2004:

Contribution Series

CS ME 2004-1 A Dance to the Music of Time, by H. J. Falcon-Lang, M. R. Gibling, M. C. Rygel, J. H. Calder and S. J. Davies; *in* Geoscientist, v. 14, p. 4-9, 2004.

CS ME 2004-2 On the Discovery of a Unique Terrestrial Faunal Assemblage in the Classic Pensylvanian Section at Joggins, Nova Scotia, by B. L. Hebert and J. H. Calder; *in* Canadian Journal of Earth Sciences, v. 41, no. 3, p. 247-254, 2004.

CS ME 2004-3 Chemical Variation in Al_2O_3-CaO-Na_2O-K_2O Space: Controls on the Peraluminosity of the South Mountain Batholith, by D. B. Clarke, M. A. MacDonald and S. Erdmann; *in* Canadian Journal of Earth Sciences, v. 41, p. 785-798, 2004.

CS ME 2004-4 A Comparison of Orogenic Gold Mineralization in Central Victoria (AUS), Western South Island (NZ) and Nova Scotia (CAN): Implication for Variations in the Endowment of Palaeozoic Metamorphic Terrains, by F. P. Bierlein, A. B. Christie and P. K. Smith; *in* Ore Geology Reviews, v. 25, p. 125-168, 2004.

CS ME 2004-5 $^{40}Ar/^{39}Ar$ dating in the Lochaber - Mulgrave area, northern mainland Nova Scotia: Implications for Timing of Regional Metamorphism and Sediment Provenance in the Late Devonian - Early Carboniferous Horton Group, by P. H. Reynolds, S. M. Barr, C. E. White and P. J. Ténière; *in* Canadian Journal of Earth Sciences, v. 41, p. 987-996, 2004.

Information Circular

IC ME 61 General Guidelines for Treasure Trove Applications (third edition, April 2004), by Registry of Mineral and Petroleum Titles, 3 pages.

Newsletter

Nova Scotia Minerals Update, volume 21, numbers 1, 2, 3 and 4.

Open File Illustration

OFI ME 2004-1 Potential Granite Aggregate Sources in the Halifax Regional Municipality area, by G. A. Prime and C. E. White, 36" x 67" colour poster.

Open File Map

OFM ME 2004-1. Shaded Relief Map of Nova Scotia, by B. E. Fisher, J. C. Poole, J. S. McKinnon and J. A. Beaumont, 2004, scale 1:500 000.

MacDonald, D. R., MacDonald, B. L., Mills, K. A. and Saunders, J. S. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 45-46.

Open File Reports

OFR ME 2004-1 Pyrophyllite Occurrences in the Coxheath area, Cape Breton Island, by D. J. Kontak, P. W. Finck and J. DeWolfe, 2004, 19 pages.

OFR ME 2004-2 Selected Mineral Occurrences in the Western Half of the Eastern Shore of the Nova Scotian mainland (a field trip guide), by G. A. O'Reilly, R. F. Mills and R. J. Horne, 2004, 25 pages.

OFR ME 2004-3 Bedrock, Glacial, Economic and Environmental Geology of the Halifax Regional Municipality (Guidebook for EdGEO Field Excursion, August 23, 2004), by T. A. Goodwin, 2004, 22 pages..

OFR ME 2004-4 Report on Potential Field Mapping Component of the Geological Mapping of the St. Marys Basin Project, Northern Mainland Nova Scotia, Phase 2 of the Targeted Geoscience Initiative, by M. S. King, 2005, 30 pages.

OFR ME 2004-5 Heavy Minerals and Sedimentary Petrology of Cretaceous Sands from the Shubenacadie Outlier, Nova Scotia, by G. Pe-Piper, R. R. Stea, S. Ingram and D. J. W. Piper, 2004, 78 pages.

Reports

Report ME 2004-1 Mineral Resources Branch Report of Activities 2003, ed. D. R. MacDonald, 206 p.

Report ME 2004-2 Mining Matters 2004, ed. D. R. MacDonald, 31 p.

Mineral Exploration Activity in Nova Scotia, 2004

P. D. McCulloch

Mineral Exploration Monitoring

Monitoring of mineral exploration activity in Nova Scotia is coordinated through the Mineral and Petroleum Titles Section of the Minerals Management Division by the author, who works out of the regional office in Stellarton, Pictou County. Regional Geologists of the Regional Services Branch offices in Coxheath (Don MacNeil), Truro (Donald Weir) and Bridgewater (Sandra Johnson) assist in the field monitoring of mineral exploration activity in their respective regions.

The monitoring process covers exploration activities throughout the province and consists of visits to company offices and exploration sites, liaison with industry personnel, and the review of current assessment reports and other material submitted by industry. Liaison with industry allows the department to maintain an awareness of current exploration activities throughout the province. Assistance or advice is provided as necessary, and any drill core generated by mineral exploration activity in the province is recorded as part of the monitoring process. This core may be recovered for archiving in the Drill Core Library in Stellarton when no longer required by the companies.

The Exploration Monitoring geologist is also responsible for auditing confidential assessment reports that are submitted in support of the renewal of exploration licences. In 2004, 141 assessment reports were received and audited for compliance with the Mineral Resources Regulations. This number is up substantially from the 96 reports submitted for assessment credit in 2003.

Mineral Exploration Activity in 2004

Mineral exploration in Nova Scotia during 2004 demonstrated a significant increase in the level of activity in comparison to the previous three years, with field expenditures estimated at $6.5 million compared with $2.9 million in 2001, $2.0 million in 2002 and $3.2 million in 2003 (Table 1, Fig. 1). This increase is primarily reflected in a renewed interest in gold exploration, with the majority of work centred on the historical gold mining districts in Halifax and Guysborough Counties. Exploration for base metals continued at roughly the same level of activity as in 2003, with the majority of work concentrated on Cu-Au exploration along the Cobequid-Chedabucto Fault Zone in northern mainland Nova Scotia. Exploration also continued for industrial minerals, although the number of active exploration programs showed a modest decrease from the level of activity of the previous two years. Overall, the amount of money available for mineral exploration was significantly higher in 2004, with most of the exploration activities carried out by the junior mining sector. This increase in exploration funding is reflected both in the continuing rise in the price of gold over the past three and a half years, which reached a high of $450 at the end of 2004, as well as the sharp increase in base metal prices that began in the fall of 2003.

Preliminary figures for the total number of general claims staked in 2004 showed a drop of 37.4% over the previous year from 18,027 to 11,275 claims (Table 1, Fig. 2). Preliminary estimates show that 11,788 claims for all commodities were in effect at the end of 2004, represented by 563 general and special licences covering an area of 190,824 ha or 1908 km^2, approximately 3.5% of the total area of the province. The amount of exploration drilling increased significantly in comparison to the previous two years, with a preliminary estimate of 17 100 m in 2004 compared with 12 200 m in 2003 and 4 100 m in 2002.

Approximately 169 companies and individuals held exploration interests (licences or options) in Nova Scotia in 2004 including 4 major, 17 junior and 42 private companies (Tables 2, 3 and 4). In addition, several mining lease holders carried out exploration and development work on leases or on unclaimed ground where these commodities did not

McCulloch, P. D. 2005. *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 47-60.

Table 1. Details of exploration and development activity in Nova Scotia 1995-2004.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	P2004
Total Field Exploration Expenditures ($)	2 843 000	5 752 000	6 700 000	5 600 000	3 800 000	3 500 000	3 100 000	3 400 000	3 200 000	6 500 000
Total Licences Issued (all categories)	698	1 127	978	711	707	606	498	551	678	563
Claims in Good Standing (new and re-issued)										
General	15 861	33 399	25 190	11 452	14 045	10 951	8 406	12 494	18 027	11 275
Special (Order in Council)										
Salt and Potash	-	214	214	820	804	255	255	500	500	-
Coal	218	311	240	253	173	-	-	102	102	102
Geothermal	158	158	158	158	158	158	158	158	158	-
Underground Gas Storage	-	-	-	106	106	106	183	183	183	201
Tailings	146	146	146	-	-	-	-	-	-	-
Other (gold, base metals)	130	130	130	130	132	10	10	10	78	210
Uranium*	(226)	(226)	(226)	(226)	(226)	(226)	(226)	(226)	(226)	(226)
Total (excluding closures and uranium licences)	16 513	34 358	26 078	12 219	15 418	11 480	9 012	13 447	19 048	11 788
Total Area Held Under Licence										
(ha)	267 312	556 186	422 150	209 132	249 586	185 838	145 886	217 679	308 348	190 824
(acres)	660 520	1 374 320	1 043 120	516 760	616 720	459 200	360 480	537 880	761 920	471 520
Work Reported for Licence Renewals ($)	1 601 639	2 376 023	3 146 899	5 385 194	2 969 047	1 136 304	2 811 393	1 457 012	1 197 208	4 270 042
Number of Assessment Reports Received	111	108	133	134	100	85	72	102	96	141

PPreliminary figures for 2004

*Parentheses around uranium claims indicate ground alienation due to the uranium moratorium

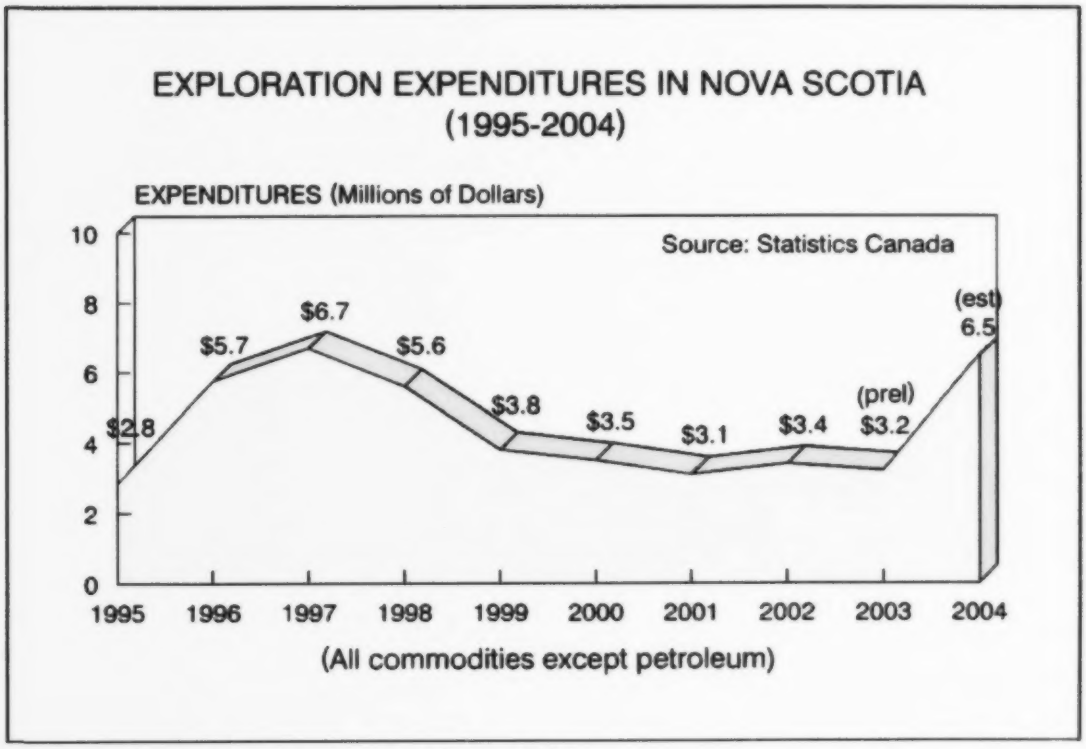

Figure 1. Exploration expenditures in Nova Scotia, 1995-2004.

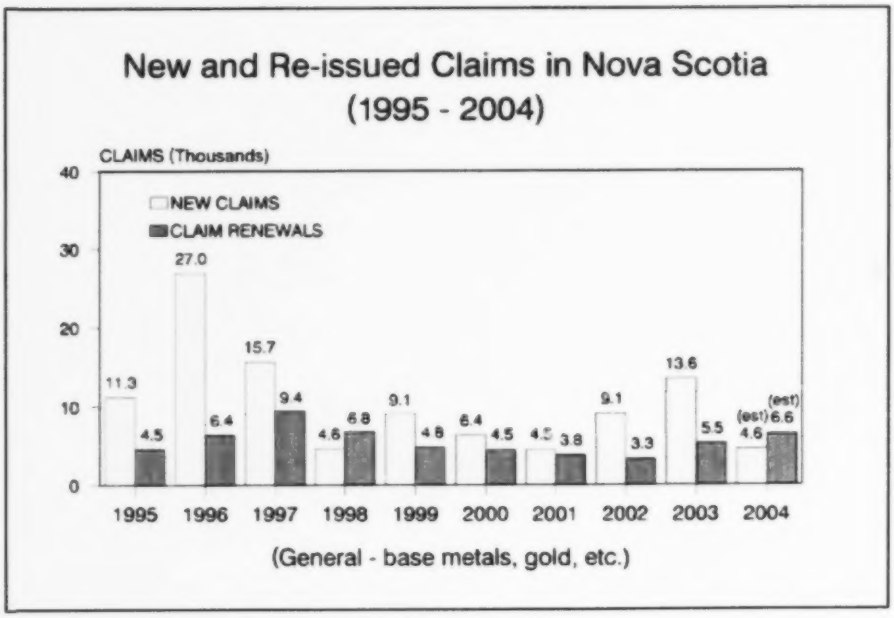

Figure 2. Claim staking in Nova Scotia, 1995-2004.

Table 2. Major companies with exploration interests (licences or options) in Nova Scotia

	2002	2003	2004
Aur Resources Incorporated	-	-	-
Georgia-Pacific Canada Incorporated		-	x
Intragaz Limited Partnership	x	x	-
Lafarge Canada Incorporated	-		
Pasminco Resources Canada Company (formerly Savage Resources Canada Limited)	-		
Statia Terminals Canada Limited	-	-	-

x indicates work performed
- company inactive
blanks indicate that the company did not hold an exploration licence in that particular year

require licences (e.g. limestone, gypsum). Organizations actively engaged in exploration during 2004 included 1 major, 11 junior and 19 private companies (Fig. 3, Table 5), as well as a number of individuals.

Exploration Activities

Gold

Exploration for gold continued to dominate mineral exploration in the province during 2004, with the level of activity showing a significant increase over 2003. The lower Paleozoic Meguma Group of southern mainland Nova Scotia continued to be the principal focus for gold exploration, with the majority of exploration work concentrated on the historical gold districts in Halifax and Guysborough Counties. A steady increase in the price of gold, as well as the continuation of an improved investment climate for the junior mining sector, have contributed to a renewed interest in the exploration and development of the Meguma gold deposits. In addition, recognition of geological environments with the potential to host IOCG deposits (iron oxide-copper-gold) along the Cobequid-Chedabucto Fault Zone in the northern mainland has also contributed to the current level of gold exploration.

Azure Resources Corporation continued a detailed evaluation of the Mooseland gold property in Halifax County during the first quarter of 2004. The company optioned the property from Globex Mining Enterprises Incorporated in September 2002 and conducted surface diamond-drilling during the first half of 2003. A decline was collared on the West Zone during the second half of 2003, followed by detailed underground mapping and sampling during the fall and the extraction of a 2000 tonne bulk sample in early 2004. Processing of the bulk sample was undertaken during the spring of 2004 at the company's Dufferin Mine property, Halifax County. Exploration activities are expected to resume in 2005 with a surface and underground diamond-drilling program and additional underground bulk sampling. In June 2003, Azure Resources also entered into an option agreement with Newfoundland Goldbar Resources Incorporated for the Dufferin Mine property. The company completed rehabilitation of the Dufferin Mine mill facilities and completed construction of an assay lab on the property to process underground samples from both the Mooseland and Dufferin Mine properties. Underground mining was resumed on the property in March 2004, along with bulk sampling and processing. An underground diamond-drilling program was completed in August 2004. The company expects to continue mining operations in 2005 and is planning to complete a surface and underground drilling program on the property.

Diamond Ventures NL, under an option agreement with Moose River Resources

Table 3. Junior companies with exploration interests (licences or options) in Nova Scotia

	2002	2003	2004
Acadian Gold Corporation		x	x
Avalon Ventures Limited		x	x
Aurogin Resources Limited	x	x	
Azure Resources Corporation		x	x
Black Bull Resources Incorporated	x	x	x
C;C Mining Corporation	-		
Corner Bay Silver Incorporated (formerly Corner Bay Minerals Incorporated)	-	-	
Diamond Ventures NL		x	x
Emerald Isle Resources Incorporated	x		
Exploration Orex Incorporated	-	-	-
Gammon Lake Resources Incorporated	-		
Globex Mining Enterprises Incorporated	x	-	x
Heartland Resources Limited	-	-	-
Landis Mining Corporation		x	-
Monster Copper Resources Incorporated		x	x
Newfoundland Goldbar Resources Incorporated	-	-	-
Pan East Petroleum Corporation	-	-	-
Regal Goldfields Limited	-	-	-
RJZ Mining Incorporated	x	-	x
Scorpio Mining Corporation		x	x
ScoZinc Limited			x
Titanium Corporation Incorporated (formerly Titanium Corporation of Canada Ltd)	x	x	x

x indicates work performed
- inactive
blanks indicate that the company did not hold an exploration license in that particular year

Incorporated, completed a preliminary diamond-drilling program on the Moose River gold property at the end of 2003 to evaluate the potential for additional gold reserves along the strike extension of the Touquoy deposit. During the first half of 2004, the company completed additional drilling on the Touquoy deposit and carried out a percussion drilling and till sampling program to evaluate the exploration potential for additional ore reserves along the strike extension of the Touquoy zone, both to the northeast of the deposit and to the southwest in the vicinity of the Higgins and Lawlor and Stillwater gold deposits. Drilling on the Touquoy deposit to date has outlined indicated and inferred reserves of 6.91 million tonnes grading 2.1g/t gold with 472,000 contained ounces of gold. The company plans to complete additional drilling on the Touquoy and Higgins and Lawlor properties in 2005.

Scorpio Mining Corporation entered into an option agreement in 2003 to evaluate the potential for re-opening the Cochrane Hill gold deposit in Guysborough County. The company completed a detailed compilation and review of previous surface and underground exploration work on the property, including diamond-drilling and various sampling programs, in late 2003 and early 2004 to confirm estimates for current gold reserves as well as the potential for developing new reserves on the property. As a result of this work, resource estimates include indicated reserves of 588,794 tons grading 0.191 oz./ton gold with 112,460 contained ounces of gold. The company has recommended the initiation of an advanced exploration program on the property, including surface and underground drilling and surface

Table 4. Private exploration companies in Nova Scotia

	2002	2003	2004
AYARCO Gold Corporation Limited		x	x
166881 Canada Incorporated	-		
3779751 Canada Incorporated	x		
Alva Construction Limited	-	x	-
Annapolis Valley Goldfields Incorporated		x	x
Asedex Minerals Corporation Limited	-	-	
Aurion Minerals Limited	-		
Blackfly Exploration & Mining		-	-
Benrock Limited		-	
Burnt Point Resources Incorporated	-	x	-
Candor Ventures Corporation	x	x	-
Cannova Goldfields Incorporated	-		
Celtic Clays		-	
Champlain Resources Incorporated	x		x
Cobequid Gold Corporation Limited			x
Conrad Brothers Limited	x	x	x
Copper Valley Holdings Limited			-
Datum Quest Explorations	-		
D&D Metal Detectors Limited			-
Dufferin Resources Incorporated	-	x	x
Ecum Secum Enterprises Limited			-
Ellsin Resources Incorporated	x	x	x
Elmsdale Landscaping Limited	-		
Erdene Gold Incorporated		x	
Gadon James Resources Company			-
Gallant Aggregates Limited	-	-	
Geosearch	-	-	-
Geostorage Associates	x	x	-
Glencoe Resources Incorporated	x	x	x
Gold 'n' Crystal Minerals	x	-	
Golden Ace Mineral Explorations Limited	-	-	x
Golden Mining Corporation			x
H & E Mullen Investments Limited	-	x	x
Hansone Limited	x	x	-
Highland Range Minerals Limited	-	-	-
Huntington Explorations Incorporated	-	-	
John Logan Enterprises Limited	-	-	-
Jubilee Minerals	x	-	-
KaoClay Resources Incorporated	-	-	-
Kelly Rock Limited	-	-	
Lynx Minerals Corporation	-	x	
MacLeod Resources Limited	x	x	x
Maritime Mica Incorporated	-		

Table 4. Private exploration companies in Nova Scotia (cont'd)

	2002	2003	2004
McLaren and Associates Geological Services			-
Meguma Resource Enterprises Incorporated	x	x	x
Minas Basin Pulp & Paper Company Limited	-	-	-
Moose River Resources Limited			x
Mt. Cameron Minerals Incorporated	-	-	x
New Road Resources Limited			-
Nycon Resources Incorporated	x	x	x
Oceanview Minerals Limited	-		
Ochter Holdings Limited		-	
Rainbow Resources Limited	-	-	x
Robert Stewart-Patterson & Associates	-		
South-Malartic Exploration Incorporated			-
The Shaw Group Limited (formerly L. E. Shaw Limited)	-	-	-
S. W. Weeks Construction Limited			-
Tri-Explorations Limited		-	-
True Metallic Explorations	-	-	-
Votix Corporation Limited	-	x	x
Yava Technologies Incorporated		x	x

x indicates work performed
- inactive
blanks indicate that the company did not hold an exploration license in that particular year

exploration to evaluate the potential for additional gold resources along the strike extension of the known reserves.

Acadian Gold Corporation acquired the mineral rights, including an option agreement on ground optioned from Mr. Henry Schenkels, for the Forest Hill gold property in 2002. The company completed a detailed compilation and technical review of the deposit in 2002 and initiated a diamond-drilling program on the property in mid-2003. Drilling continued on the property during the first half of 2004 and plans are in place to proceed with underground diamond-drilling and bulk sampling in 2005. Resource estimates to date have increased reserves to an estimated 588,794 tons grading 0.191 oz./ton with 112,460 contained ounces of gold. The company has also carried out preliminary exploration programs on a number of other gold properties throughout Halifax and Guysborough Counties during 2004, including several properties recently acquired from Goldenville Mining Corporation as a result of an agreement in mid-2004 to acquire the privately owned company.

Highlights of the work undertaken by Acadian Gold in Halifax County include rotary percussion drilling, till sampling and rock sampling in an area immediately west of the Beaver Dam gold

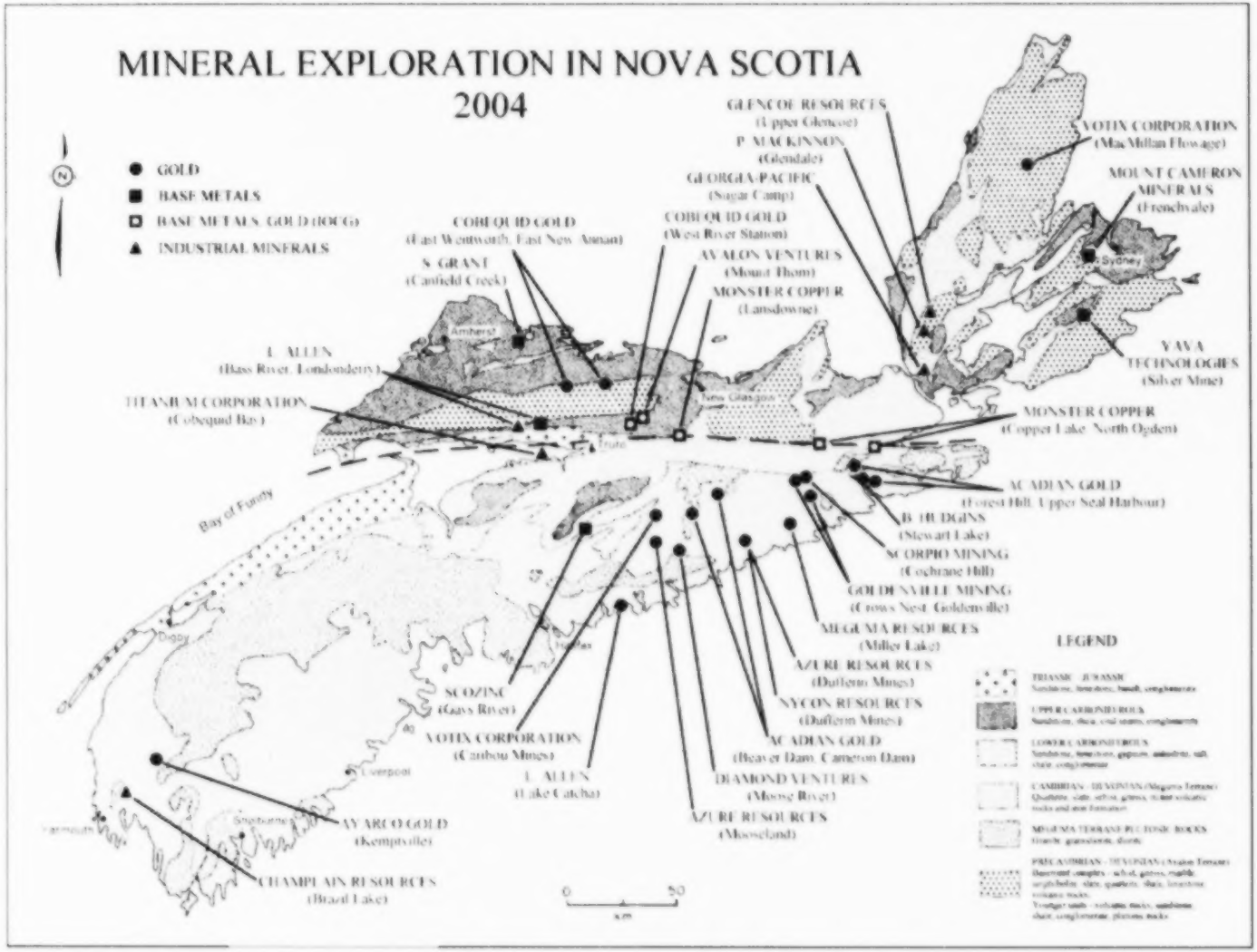

Figure 3. Mineral exploration programs in Nova Scotia, 2004.

property, diamond-drilling in an area immediately to the west of the former Cameron Dam gold district along the Cameron Dam-Cochrane Hill anticline, and diamond-drilling on the Lake Lode zone on the eastern extension of the Caribou Mines gold property. Other work, including prospecting and geological mapping, rock sampling, and reconnaissance soil and stream sediment sampling, was completed in the immediate vicinity of the Killag Mines and Ragged Falls gold properties, in an area immediately west of the Fifteen Mile Stream gold property, and in an area immediately east of the Moose River and Mooseland gold properties. Work carried out by the company in Guysborough County included diamond-drilling on the eastern extension of the Boston-Richardson gold deposit at Upper Seal Harbour, diamond-drilling in the vicinity of Costley Lake, Garry Lakes and Lawlors Lake east of the Forest Hill gold property and in the Big Lake area south of the Forest Hill gold property, and diamond-drilling in the immediate vicinity of the former Goldenville Mine property. Prospecting, rock sampling, and soil sampling were also completed in an area immediately east of the former Crows Nest mine property along the west strike extension of the Cochrane Hill gold property. The company also completed preliminary field work consisting of reconnaissance till sampling in the MacMillan Flowage and Indian Brook areas of Inverness and Victoria Counties in the central Cape Breton Highlands.

Nycon Resources Incorporated completed a diamond-drilling program on the Salmon River gold property in Halifax County, and Azure Resources Corporation, in an option agreement with Meguma Resource Enterprises Incorporated, completed prospecting and geological mapping on the Miller Lake gold property in Guysborough County. Hudgtec Consulting Limited continued a detailed evaluation of a large northwest-trending fault zone in the Stewart Lake area south of Forest Hill, Guysborough County. Work on the property included prospecting, geological mapping, and rock, till and stream sediment sampling. AYARCO Gold Corporation Limited completed additional soil geochemical sampling on the Kemptville gold property in Yarmouth County.

Cobequid Gold Corporation Limited completed a preliminary exploration program for gold and silver on several properties in the East Wentworth-Earltown area of Colchester County, consisting of prospecting, geological mapping and rock, soil and stream sediment sampling. The area is underlain by volcanic and sedimentary rocks of the Middle Devonian Fountain Lake Group in the eastern Cobequid Highlands.

Rainbow Resources Limited completed additional work on the Widow Point gold prospect in Guysborough County, consisting of prospecting, geological mapping and soil sampling, and Conrad Brothers Limited completed additional prospecting and trenching at Lake Charles in Halifax County. A preliminary evaluation and technical review of the Upper Seal Harbour property was undertaken during 2004 by Orex Exploration Incorporated, and Meguma Resource Enterprises Incorporated completed additional prospecting and rock sampling on the Ecum Secum gold property in Halifax County.

A number of small exploration programs were also completed on several properties throughout the Meguma Group by several individuals and private interests. Scott Grant carried out prospecting and rock sampling on the Harrigan Cove and Ecum Secum gold properties in Halifax County, and on the Renfrew gold property in Hants County. Lindsay Allen completed prospecting and rock sampling on the Oldham gold property in Halifax County, and Dennis Forgeron carried out prospecting and geological mapping on the Country Harbour gold property in Guysborough County. Albert Crouse carried out prospecting, trenching and rock sampling on the North Brookfield gold property in Queens County and Allen Hooper completed a similar program on the Molega gold property in Queens County. Work in other areas of the province was undertaken by William Burrell at Gold Brook in Victoria County, consisting of prospecting and pitting, and Scott Grant completed prospecting and rock sampling in the Whycocomagh Mountain area in Inverness County.

Base Metals

Exploration for base metals showed a moderate increase in the level of activity over the previous three years. The increase in activity over the year was reflected primarily in a shift in focus to new

Table 5. Mineral exploration programs in Nova Scotia, 2004.

COMPANY/INDIVIDUAL	LOCATION	COMMODITY	PROGRAM
A. Crouse	North Brookfield, Queens County	Gold	Prospecting, trenching, rock sampling
A. Hooper	Molega, Queens County	Gold	Prospecting, trenching, rock sampling
Acadian Gold Corporation	Beaver Dam area, Halifax County	Gold	Percussion drilling, till and rock sampling
	Cameron Dam, Halifax County	Gold	Diamond-drilling
	Caribou Mines, Halifax County	Gold	Diamond-drilling
	Killag Mines, Halifax County	Gold	Prospecting, geological mapping, rock sampling
	Ragged Falls, Halifax County	Gold	Prospecting, geological mapping, rock sampling
	Fifteen Mile Stream area, Halifax County	Gold	Prospecting, geological mapping, rock sampling
	Moose River area, Halifax County	Gold	Prospecting, geological mapping, rock sampling
	Mooseland area, Halifax County	Gold	Prospecting, geological mapping, rock sampling
	Upper Seal Harbour, Guysborough County	Gold	Diamond-drilling
	Forest Hill, Guysborough County	Gold	Diamond-drilling
	Goldenville, Guysborough County	Gold	Diamond-drilling
	Crows Nest, Guysborough County	Gold	Prospecting, geological mapping, rock sampling
	MacMillan Flowage area, Inverness and Victoria Counties	Gold	Till sampling
Avalon Ventures Limited	Mount Thom area, Colchester County	Copper, gold	Prospecting, geological mapping, surface and airborne geophysical surveys, soil sampling, diamond-drilling
	Upper Kemptown-West River Station area, Colchester and Pictou Counties	Copper, gold	Prospecting, geological mapping, rock sampling, soil sampling, airborne geophysics
AYARCO Gold Corporation	Kemptville, Yarmouth County	Gold	Soil sampling
Azure Resources Corporation	Mooseland, Halifax County	Gold	Underground bulk sampling
	Dufferin Mines, Halifax County	Gold	Underground bulk sampling and diamond-drilling
	Miller Lake, Guysborough County	Gold	Prospecting, geological mapping
B. Hudgins	Round Lake area, Guysborough County	Copper, gold	Prospecting, geological mapping, rock sampling stream sediment sampling
Champlain Resources Incorporated	Brazil Lake, Yarmouth County	Quartz, mica, spodumene	Metallurgical studies
Cobequid Gold Corporation	East Wentworth-Earltown area, Colchester County	Gold, silver	Prospecting, geological mapping, rock sampling, till sampling, stream sediment sampling
Conrad Brothers Limited	Lake Charles, Halifax County	Gold	Prospecting, trenching
D. Forgeron	County Harbour, Guysborough County	Gold	Prospecting, geological mapping

Table 5. Mineral exploration programs in Nova Scotia, 2004 (cont'd).

COMPANY/INDIVIDUAL	LOCATION	COMMODITY	PROGRAM
Diamond Ventures NL	Moose River, Halifax County	Gold	Diamond-drilling, percussion drilling
Elk Explorations Limited	Bass River, Colchester County	Barite	Prospecting, rock sampling
	Cross Roads Ohio, Antigonish County	Base metals, gold	Prospecting, rock sampling, soil sampling
	Oldham, Halifax County	Gold	Prospecting, rock sampling
Exploration Orex Incorporated	Upper Seal Harbour, Guysborough County	Gold	Compilation work
Georgia-Pacific Canada Incorporated	Sugar Camp, Inverness County	Anhydrite	Percussion drilling, rock sampling
Glencoe Resources Incorporated	Upper Glencoe, Inverness County	Carbonates (marble)	Rock sampling, review of previous drilling
Golden Ace Mineral Explorations Limited	MacNeils Lake area, Cape Breton County	Base metals, gold	Prospecting, geological mapping, rock sampling
Hudgtec Consulting Limited	Stewart Lake area, Guysborough County	Gold	Prospecting, geological mapping, rock sampling, till sampling, stream sediment sampling
H. Schenkels	Polson Brook, Antigonish County	Copper, gold	Trenching, rock sampling
M. Cullen	Staples Brook, Colchester County	Coal	Diamond-drilling
	Kemptown, Colchester County		
Meguma Resource Enterprises Inc.	Ecum Secum, Halifax County	Gold	Prospecting, rock sampling
Monster Copper Resources Incorporated	Bass River, Colchester County	Copper, gold	Prospecting, rock sampling
	Copper Lake, Antigonish County	Copper, gold	Prospecting, geological mapping, ground geophysical surveys, rock sampling, soil sampling
	Lansdowne, Pictou County	Copper, gold	Prospecting, geological mapping, airborne geophysics, rock sampling, soil sampling
	North Ogden, Guysborough County	Copper, gold	Prospecting, geological mapping, airborne geophysics, rock sampling, soil sampling
Mt. Cameron Minerals Incorporated	Frenchvale, Cape Breton County	Base and precious metals	Prospecting, diamond-drilling
Nycon Resources Incorporated	Salmon River, Halifax County	Gold	Diamond-drilling
P. MacKinnon	Glendale area, Inverness County	Carbonates (marble)	Prospecting, geological mapping, trenching, rock sampling

Table 5. Mineral exploration programs in Nova Scotia, 2004 (cont'd).

COMPANY/INDIVIDUAL	LOCATION	COMMODITY	PROGRAM
Rainbow Resources Limited	Widow Point, Guysborough County	Gold	Prospecting, geological mapping, soil sampling
ScoZinc Corporation	Gays River, Halifax County	Base metals	Prospecting, diamond-drilling
Scorpio Mining Corporation	Cochrane Hill, Guysborough County	Gold	Review and compilation of previous work
S. Grant	Ecum Secum, Halifax County	Gold	Prospecting, rock sampling
	Harrigan Cove, Halifax County	Gold	Prospecting rock sampling
	Renfrew, Hants County	Gold	Prospecting rock sampling
	Whycocomagh Mountain, Inverness County	Gold	Prospecting rock sampling
Titanium Corporation Incorporated	Cobequid Bay area, HantsCounty	Mineral sands (titanium)	Drilling, mineralogical studies
W. Burrell	Gold Brook, Victoria County	Gold	Prospecting, pitting
Yava Technologies Incorporated	Silver Mine, Cape Breton County	Lead	Review and analysis of field work

geological environments associated with the potential for the discovery of Olympic Dam style 'iron, oxide-copper-gold' (IOCG) deposits along the Cobequid-Chedabucto Fault Zone in central mainland Nova Scotia. Numerous Cu-Fe occurrences, with other mineral associations including cobalt and precious metals, lie along this major structural zone. Exploration also focused on known mineral occurrences in various geological environments in mainland Nova Scotia and Cape Breton Island.

Monster Copper Resources Incorporated continued a detailed exploration program to evaluate the base metal and precious metal potential of several properties along the Cobequid-Chedabucto Fault Zone in central mainland Nova Scotia. The company, along with exploration partner Wallbridge Mining Company, began work on the project in 2002 to evaluate the potential for IOCG deposits in iron-rich breccia occurrences in Nova Scotia. The company carried out geological studies, ground geophysical surveys, prospecting, and rock geochemical sampling on several properties in 2003 and expanded on the exploration program in 2004 to evaluate properties in the Lansdowne area in Pictou County, the Copper Lake area in Antigonish County, and the North Ogden area in Guysborough County. Work on these properties included prospecting, geological mapping, and rock and soil sampling. In addition, ground geophysical surveys were completed in the Copper Lake area and an aeromagnetic survey was completed in the Lansdowne and North Ogden areas. Additional work was also completed in the Bass River area in Colchester County, consisting of prospecting and rock sampling.

Avalon Ventures Limited entered into an option agreement with private interests in the fall of 2003 to evaluate the potential for IOCG deposits in the Mount Thom area northeast of the town of Truro, bordering Pictou and Colchester Counties. The project area is host to the Mount Thom Cu-Co-Au prospect. Preliminary work on the property included prospecting and rock geochemical sampling. The company continued with a large-scale exploration program on the property in 2004 which included prospecting, geological mapping, soil geochemical sampling, surface and airborne geophysical surveys and diamond-drilling. The company also entered into an option agreement

with Wallbridge Mining Company and Cobequid Gold Corporation Limited in 2003 to evaluate the potential for IOCG deposits in the Upper Kemptown-West River Station area along the Cobequid-Chedabucto Fault Zone covering the area to east and west of the Mount Thom property. The 2004 exploration program concentrated on detailed prospecting and geological mapping, rock and soil geochemical sampling, and extension of the airborne geophysical survey completed on the Mount Thom property.

Using the IOCG model, a preliminary assessment was undertaken during the year by Bruce Hudgins in the Round Lake area, Guysborough County, consisting of prospecting, geological mapping, rock sampling and stream sediment sampling. Henry Schenkels carried out prospecting and rock sampling in the Polson Brook area in Antigonish County.

ScoZinc Limited continued exploration work in the Gays River area north of Halifax County to evaluate the potential for outlining additional Pb-Zn reserves in the Lower Carboniferous sediments of the Windsor Group in the immediate vicinity of the Gays River Pb-Zn deposit. Work on the property included prospecting and diamond-drilling. Golden Ace Mineral Explorations Limited completed a preliminary evaluation of the gold and base metal potential in the vicinity in the MacNeils Lake area near Oceanview, Cape Breton County. Work on the property included prospecting, geological mapping, and rock sampling.

Yava Technologies Incorporated continued a detailed evaluation of the former Yava lead deposit located near Silver Mine in Cape Breton County. The property hosts a 4.5 million ton stratabound lead deposit in Carboniferous sandstones grading 2.79% Pb with minor zinc levels. The company is currently evaluating the feasibility of utilizing *in situ* leach mining to recover the low-grade lead. Diamond-drilling and a series of test wells were completed in the fall of 2003, and a comprehensive review and analysis of the results of the field work were undertaken during 2004.

Mt. Cameron Minerals Incorporated, under an option agreement with Mountain Lake Resources Incorporated, initiated an exploration program for base metals and precious metals in the Frenchvale area, Cape Breton County, in 2004. Work on the property included prospecting and diamond-drilling. Elk Explorations Limited completed a preliminary exploration for base metals and gold in the Cross Roads Ohio area in Antigonish County consisting of prospecting, rock sampling and soil sampling.

Industrial Minerals

Exploration for industrial minerals continued at approximately the same level of activity as in the previous three years, with activity focused on commodities including titanium, carbonate resources, pegmatites (quartz, mica, spodumene), barite and gypsum.

Titanium Corporation Incorporated continued a detailed evaluation of the titanium-bearing heavy mineral sands in the Cobequid Bay area near Maitland, Hants County. The company completed additional drilling, sample analysis and mineralogical studies during the summer to evaluate an area of titanium-bearing sands outlined in a previous drilling program. Georgia-Pacific Canada Incorporated completed a percussion drilling program and rock sampling to evaluate anhydrite resources in the immediate vicinity of the company's Sugar Camp gypsum quarry located north of Port Hawkesbury in Inverness County.

Glencoe Resources Incorporated completed additional work on the Upper Glencoe carbonate deposit located approximately 5 km south of Upper Glencoe, Inverness County. Work on the property included a detailed review of previous drilling in the area and rock sampling. Perry MacKinnon completed a preliminary examination of a carbonate occurrence in the Cameron Mountain Road area north of Glendale, Inverness County, during the year, consisting of prospecting, geological mapping, trenching and rock sampling.

Champlain Resources Incorporated continued a detailed evaluation of the Brazil Lake pegmatite deposit in Yarmouth County during the year. Work on the property consisted of the continuation of metallurgical studies on the quartz, muscovite and spodumene components of bulk samples collected prior to 2004. Elk Explorations Limited carried out prospecting and rock sampling for barite in the immediate vicinity of the Bass River barite showing north of Bass River in Colchester County.

Coal

Michael Cullen continued to explore for coal resources in the Staples Brook and Kemptown areas, Colchester County, during the fall of 2003. The work program in 2004 consisted of additional diamond-drilling on the two properties.

A Placer Gold Investigation at Tangier, Nova Scotia

R. F. Mills, R. R. Stea, P. K. Smith and T. A. Goodwin

Introduction

In the summer of 2003 an excavator levelling a hillside exposed an adit in till approximately 300 m south of the former mine workings at Tangier (NTS 11D/15; Fig. 1). This adit (Fig. 2), unsupported by timber, provides ingress to overburden that is very hard and well cemented. The sinuous tunnel was measured to be 53 m long. It exists at a till contact between 'drumlin-like' hybrid till and moraine, and an older till (Stea *et al.*, this volume, p. 101-115). It may not be the first such adit discovered in the area.

The indication that placer gold may have been mined in the Tangier vicinity led to an investigation by the Nova Scotia Department of Natural Resources in the 2004 field season, to sample till in the immediate vicinity of the adit and buried fluvial bar material close to the adit, as well as between the adit and the known lode-gold ore zone, to determine the status of these media as possible sources of placer gold.

Surficial Geology

Deposits of glacial till generally overlie the gold-bearing, Cambo-Ordovician Meguma Group strata. Gold and other minerals, enriched in arsenic, copper, lead, zinc, tungsten, bismuth, tellurium and iron, commonly characterize the bedrock mineralogy of these Nova Scotia gold districts (Kontak and Smith, 1993). Minerals such as these are commonly concentrated in surficial materials mechanically dispersed down-ice from known mineralized zones (Coker *et al.*, 1988). Dispersal distances vary in Nova Scotia from hundreds of metres to several kilometres down-ice from source (Stea and Finck, 2001).

History of Placer Mining at Tangier (from O'Reilly *et al.*, 2004)

Tangier was one of the most prolific, successful gold districts in Nova Scotia. It remains one of the province's best bets for underground development today. Coxheath Gold Holdings Ltd. drifted 5 km of tunnels and declines under the hill northwest and northeast of Copper Lake in the late 1980s, which corresponds to the hinge of the local Tangier anticline.

Tangier is the place primarily responsible for the first great Nova Scotian gold rush, as gold was first discovered here in commercial quantity when Peter Mason, a local farmer and part-time sea captain, stopped in 1861 to water some beasts of burden in a local stream and discovered yellow metal in the stream bed. This discovery was described in a letter by Joseph Howe to the Earl of Mulgrave and led to the development of the mining recorder's office and a Department of Mines (J. Howe, 1861). The discovery was described in Joseph Howe's letter as being in Tangier River. However, Tangier River is approximately 500 m east of this location. Conversations with local persons who are distant relatives of Peter Mason place the actual location of the discovery in a small stream running north of Rush Lake.

Placer deposition has been documented in this area in the past. In 1863, Copper Lake (Fig. 1) was drained completely and placer nuggets were mined on the bottom of the lake bed (Nova Scotia Department of Natural Resources, 1865). Malcolm (1921) described the largest placer nugget ever recovered in Nova Scotia to have been found, "in the vicinity of Rush Lake." This placer nugget was described to have weighed almost two pounds.

Mills, R. F., Stea, R. R., Smith, P. K. and Goodwin, T. A. 2005 *in* Mineral Resources Branch, Report of Activities 2004. Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 61-67.

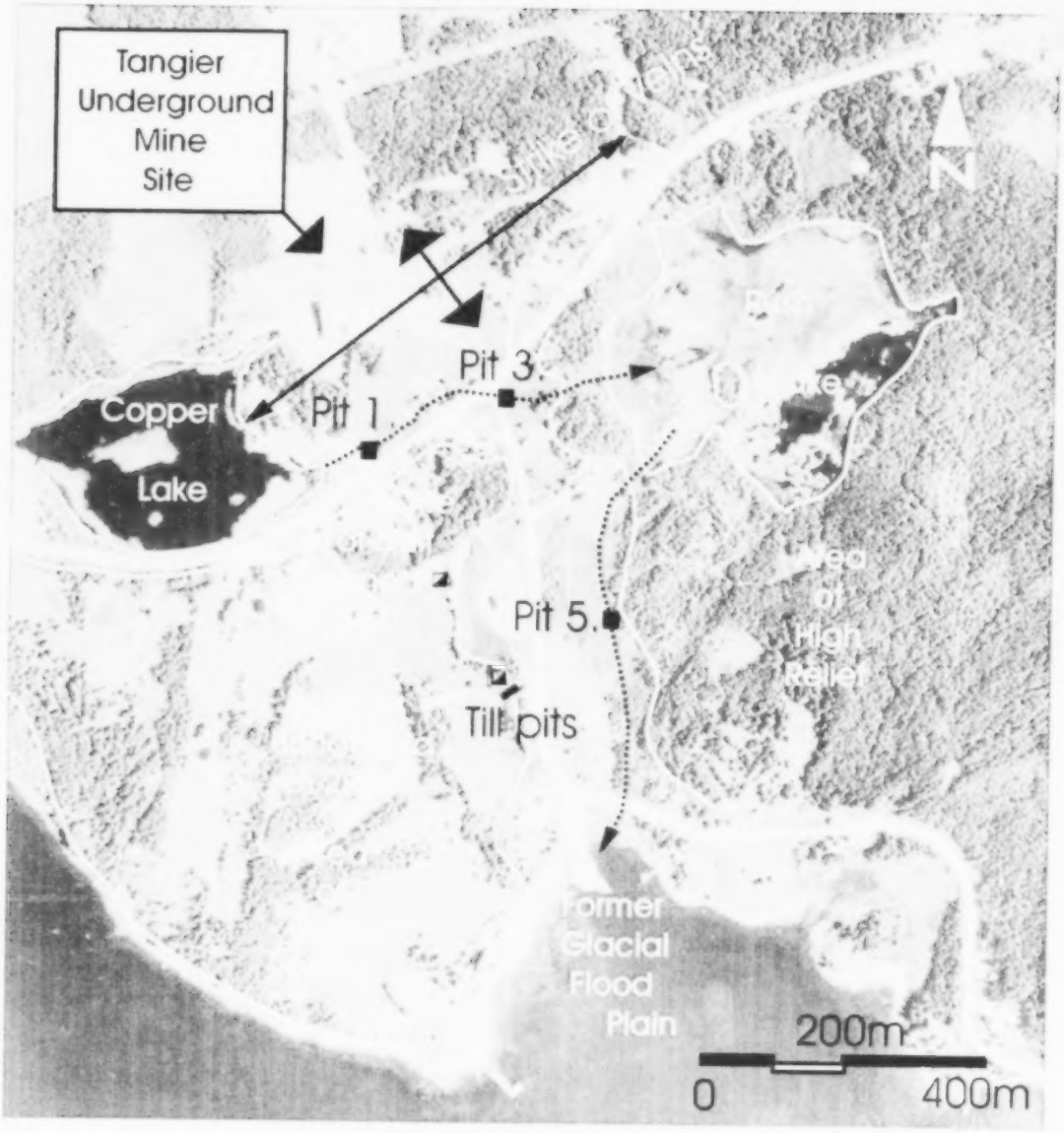

Figure 1. Air photo of the Tangier site with labels to show features of interest

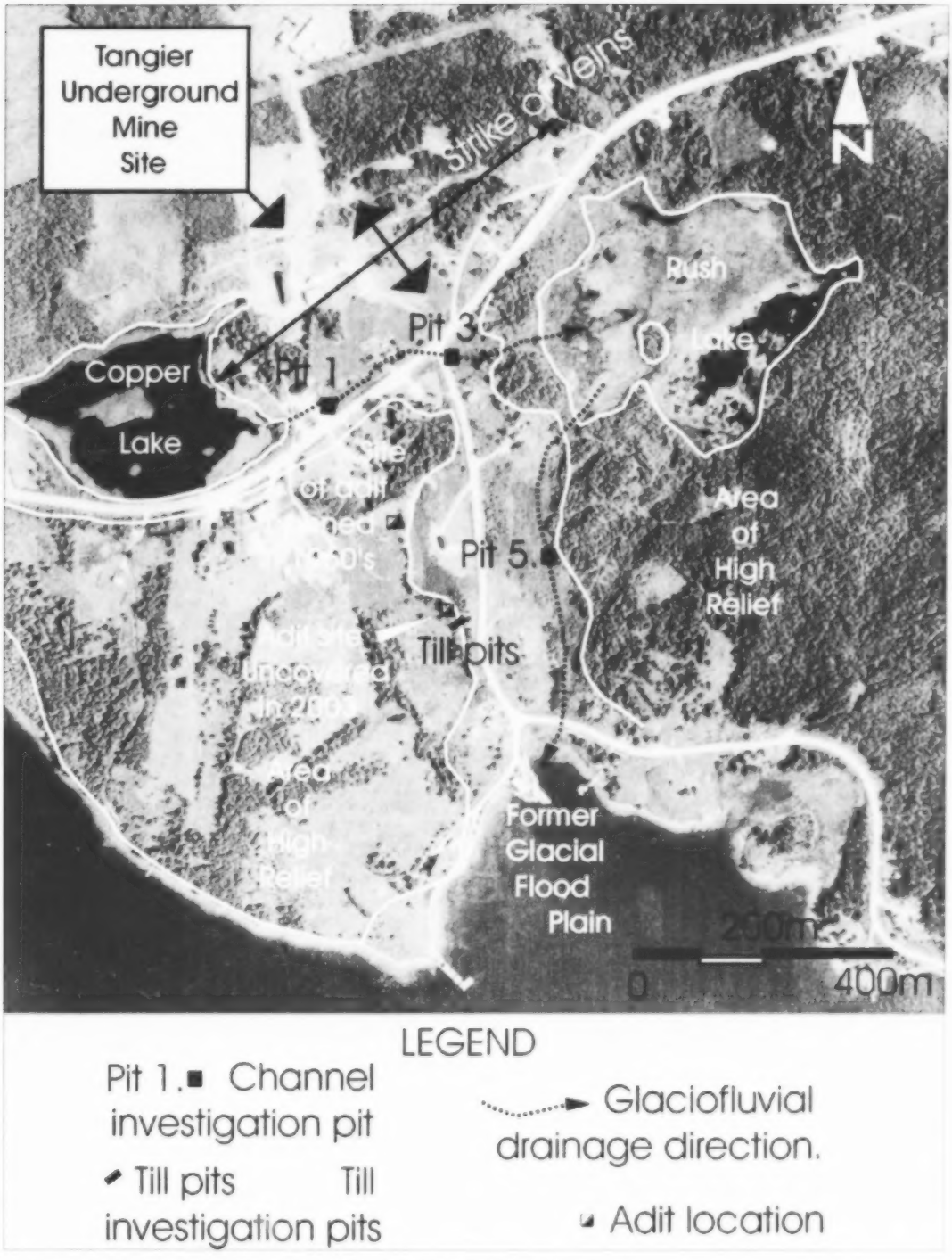

Figure 1. Air photo of the Tangier site, with labels to show features of interest

Figure 2. Photograph of the adit discovered during excavation in 2003.

Little is documented about these early placer discoveries in the Tangier vicinity. At the time, the newly created Department of Mines, and the royalties due to be paid to the same, probably contributed to a lack of reporting on the part of many of these early miners. There was no other known placer development history for the Tangier area until the 2003 adit discovery.

Local landowner Graeme Cooper described what may have been a second adit only a few tens of metres north of this location. This other adit was opened in the 1960s and was quickly re-buried.

Methodology

Five pits were dug as close to bedrock as possible, in some cases to bedrock, at sites that followed the direction of glacio-fluvial drainage south of the former Tangier mine site. This included two pits between Copper Lake and Rush Lake, and a third pit downstream from the Rush Lake outflow to investigate fluvial channel and bar material for gold content (Fig. 1). Material from two of the pits, pit 1 and pit 5, was sluiced as part of the 2004 field program. These two pits, together with pits investigating tills overlying these deposits, form a continuous section from bedrock to the soil horizon, and form a rectangle approximately 500 m long and 200 m wide, oriented north-south from the southern extremity of the Tangier hard-rock ore zone in the north (pit 1 - Hall; pit 3 - John Towill property), to the newly discovered placer adit in the southwest corner (Cooper property till excavation), and the vicinity of interpreted glacio-fluvial egress from Rush Lake toward Tangier Harbour (pit 5 - Horgan Property). Two other pits were dug and sampled (pits 2 and 4) but those samples were not investigated as part of the 2004 field program.

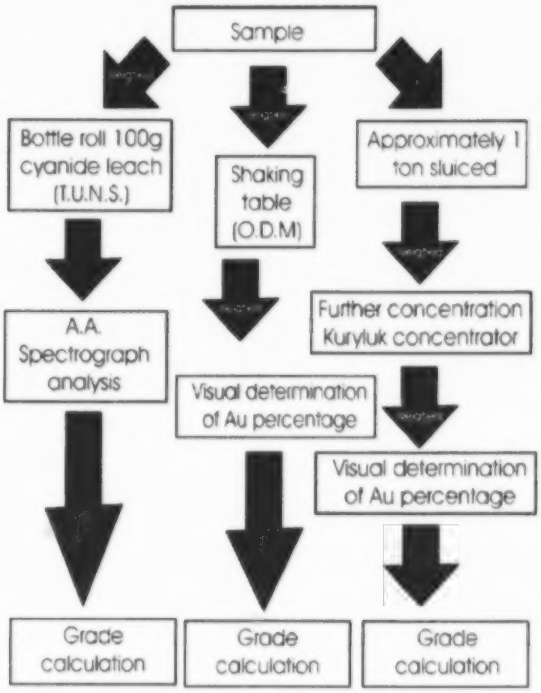

Figure 3. Flow chart showing the methods of sample processing used in this study.

A flow chart is presented in Figure 3 to outline sample processing methods. The (channel investigation) pits were profiled by the excavator, by laying the section out in piles as the excavator dug deeper. The geology of the section was recorded during this exercise. Piles from the excavation were put through a 'long tom' sluice, 0.35 m wide with a ten foot run, which was set up with a rise to run of approximately 1%. The sluice had no riffles, but consisted of a bed of 2 cm aluminum expanded metal over 'v' ribbed rubber matting. This was used to produce a concentrate from approximately 1.0 m^3 of material taken from the pit profiles, starting at the bottom, as close to bedrock as possible. Measurements for sluice input were taken using the excavator bucket, which was 1.25 m^3.

Concentrates were visually examined on site. They were then weighed and further concentrated in Sackville, Nova Scotia, by Kuryluk Enterprises. These were visually examined for gold content and weighed for grade calculation per m^3 by weight. Raw (unconcentrated) samples were also sent to Overburden Drilling Management in Ottawa, Ontario, for visual analysis and assay to compare to calculated grades. Analyses were done at the

Table 1. Results from analysis of heavy mineral concentrates (HMC).

	Bulk Input kg	HMC weight (grams)	grams HMC/ton	Au analysis (ppm)**	g Au/ton	*$13.69 US	ore (>$3 ton)
T1-1Hall_Till (-60+100)	95.2	2.076	21.81	1999	0.04359	$.596 ton	sub-ore grade
T1-1Hall_Till (-20+60)	1250 estimate	11.925	9.54	4579	0.0436	$.596 ton	sub-ore grade
Tan_Horgan (-20+60)	1000 estimate	5.561	5.561	944	0.0052	$.07 ton	sub-ore grade
Tan_Cooper adit_profile	40.2	7.757	192.96	2424	0.4677	$6.40 ton	ore grade

*Gold valued at $13.69 US per gram ($425.80 US per ounce).
**Analyses by Minerals Engineering Center - Dalhousie University.

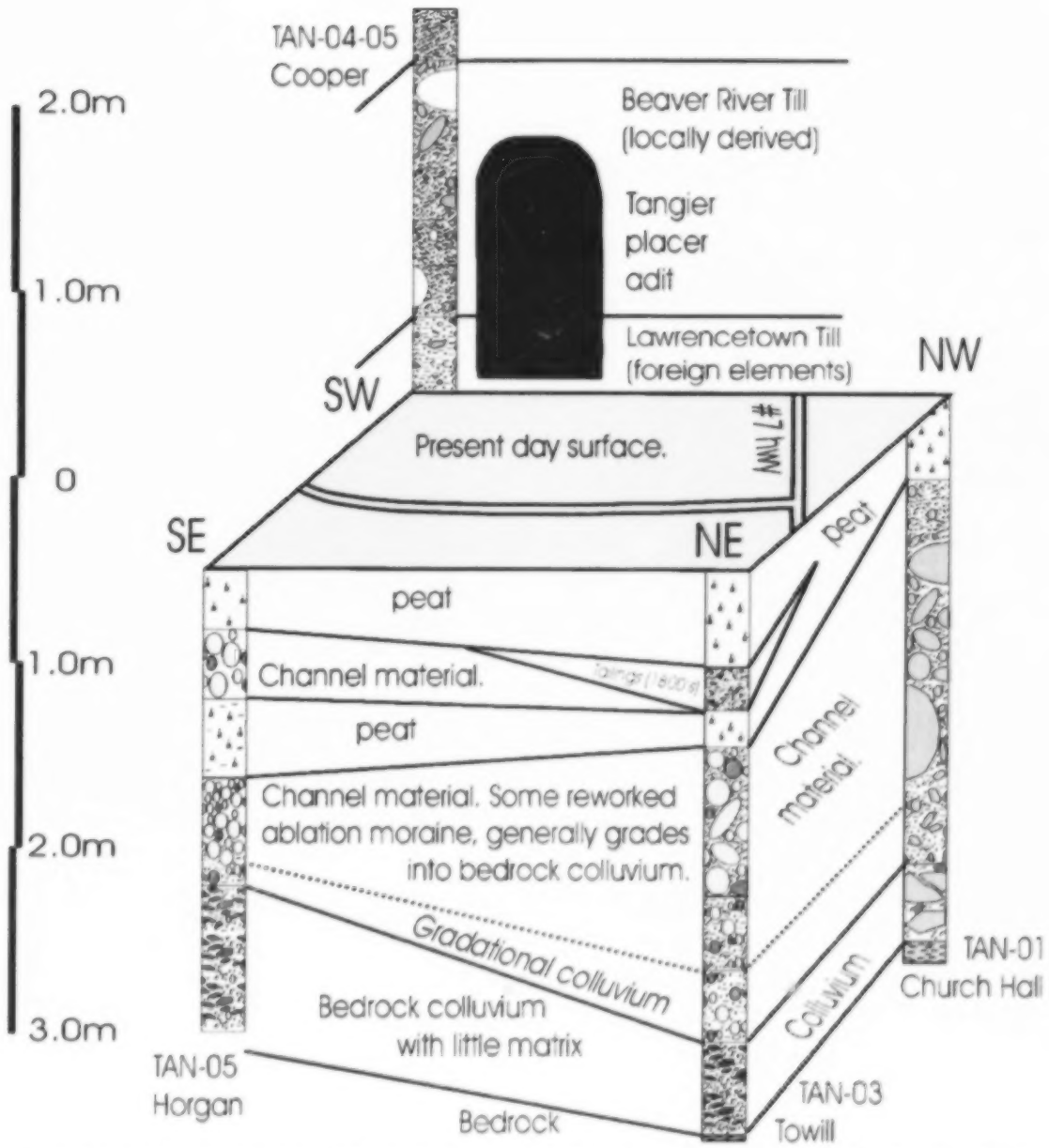

Figure 4. Correlation diagram of surficial deposits revealed in the three till investigation pits, and in the till section where the adit is located

Dalhousie University Minerals Engineering Centre by atomic adsorption spectroscopy, after a dissolution by cyanide leach.

Results

The sluicing runs for samples taken from the pits revealed that braided stream, channel and bar material did not contain gold in any quantity that would make them candidates for placer development (Table 1).

Sections

The channel sections are all buried beneath a modern peat layer (Fig. 4). When this top layer was removed in pit number TAN-03 it revealed a layer of 1860s- to 1880s-vintage tailings overlying an older peat layer. Under this layer is a sequence of braided to meandering bar material. This sediment consists mainly of poorly sorted, sub-rounded to well rounded clasts, from sand and small gravel size to large boulders the size of pianos. This part of the section was usually marked at the top by what may be interpreted as ablation material, consisting of a framework of predominantly large rounded boulders without much matrix. The framework is composed of almost entirely Goldenville Formation meta-psammite (greywacke) but a few granitiod clasts are present, as well as rare foreign clasts consisting of well rounded, very hard volcanics, presumed to be derived from the Antigonish Highlands. The stratigraphy in TAN-03 is essentially repeated in hole TAN-05 (Horgan property), with minor differences.

The section at the Church Hall (TAN-01) consisted of a peaty layer over a thick layer of very large ablation boulders (up to piano size) grading into colluvium boulders with very little matrix, which graded into a broken colluvium to local (slatey coloured) till, hybrid toward the bottom.

Samples taken from the Cooper property are discussed in detail by Stea *et al.* (this volume, p. 101-115).

Discussion

Development close to the stream between Copper Lake and Rush Lake, both residential and from past mining, has filled much of the original stream bed with broken muck and tailings. Underlying this, however, is very coarse angular colluvium mixed with till down to bedrock. Quartz clasts from known gold-bearing quartz veins are commonly found closer to bedrock.

The channel bar material samples did not return gold. This could be due to a number of circumstances, including the following. (1) The sluice was set up at a relatively aggressive angle. Sluices are operator dependant, and the sluicing performed in this case was by relatively inexperienced operators, new to the task. (2) The till in pits TAN-01, TAN-03 and TAN-05 were Meguma-derived tills, but pits were caving in wet ground so little of the material returned by the excavator was very locally derived bedrock material, close to the bedrock-overburden interface. The sample sizes at the deepest parts of the pits were too small to return reliable results. (3) It is possible there is no coarse gold in the channel bar material.

The till section on the Cooper property returned anomalous gold concentrations in excess of ore-grade levels.

References

Coker, W. B., Sexton, A., Lawyer, I. and Duncan, D. 1988: Bedrock, till and soil geochemical signatures at the Beaver Dam gold deposit, Nova Scotia, Canada; *in* Prospecting in Areas of Glaciated Terrain 1988, eds. D. R. MacDonald and K. A. Mills; Proceedings of Symposium sponsored by Canadian Institute of Mining and Metallurgy, Halifax, Nova Scotia, p. 241-254.

Howe, J. 1861: A letter to the Earl of Mulgrave; Nova Scotia Department of Natural Resources, Miscellaneous Report, MR-H-138, 3 p.

Kontak, D. J. and Smith, P. K. 1993: A metaturbidite-hosted lode gold deposit: the Beaver Dam deposit, Nova Scotia. I. vein paragenesis and mineral chemistry; Canadian Mineralogist, v. 31, p. 471-522.

Malcolm, W. 1912: The Gold Fields of Nova Scotia; Geological Survey of Canada, Memoir 156, 384 p.

Nova Scotia Department of Mines 1865: Report on the Mines 1865; Annual Report 1865.

O'Reilly, G. A., Mills, R. F. and Horne, R. 2004: Selected mineral occurrences in the western half of the Eastern Shore of the Nova Scotian mainland; Field Guide of the Nova Scotia Prospectors Association, June 12-13, 2004, 24 p.

Stea, R. R., Mills, R., Smith, P. K. and Goodwin, T. 2005: Can till be mined for gold in Nova Scotia? *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 101-115.

A Summary Report on the Work Undertaken for the Nova Scotia Component of the Targeted Geoscience Initiative (Phase 2)[1]

R. D. Naylor, D. C. Brisco, B. E. Fisher, P. S. Giles[2], T. A. Goodwin and D. J. Kontak

Introduction

The Targeted Geoscience Initiative (TGI) is a national program designed to assist and promote mineral and energy exploration. Work on the second phase of this program (TGI-2) began during the summer of 2003 and the program ends April 1, 2005.

The Nova Scotia component of the current TGI program is a mapping and geological resource evaluation project which has focused on NTS areas 11E/06 and 11E/07 (see Fig. 1). The project includes new bedrock mapping, digital compilation of historical mapping data, mineral deposit research, geophysical modelling and regional geochemistry. A useful overview of the project is provided by Naylor *et al.*, 2004.

The purpose of this report is to provide a brief summary of the work undertaken during 2004. The report also includes a list of the products that will be generated by this project.

Geological Mapping

The study area holds significant mineral and hydrocarbon resource potential. Higher quality bedrock maps and improved stratigraphic and structural models, however, are required to guide exploration efforts.

During the summer of 2004 we undertook selected bedrock mapping of Carboniferous strata on NTS areas 11E/06 and 11E/07. Particular attention was paid to defining stratigraphic boundaries and resolving structural questions. Work was also undertaken on locating and mapping small mafic intrusives that locally appear to cut Carboniferous sediments.

Both upper and lower Carboniferous strata can be found within the study area. The Upper Carboniferous strata have been assigned to the Cumberland Group. Based on our mapping over the last two field seasons we are able to subdivide the Cumberland Group into six formations. From oldest to youngest the formations are: Boss Point, Parrsboro, Totten Brook, Chiganois River, Cross Road and Debert River. The Boss Point and Parrsboro formations have been previously recognized outside the map area. The other formations are new subdivisions of the Cumberland Group.

The Lower Carboniferous within the project area includes strata assigned to the Mabou, Windsor and Horton groups. Lithostratigraphic subdivision of the Mabou strata has proven very difficult. In part this is due to the variable degree of alteration found within the unit. Mabou strata range from relatively unaltered to highly altered with extensive iron carbonate mineralization. In addition, palynological analysis of Mabou strata has been largely unsuccessful.

Work on the Windsor Group was generally confined to examining contact relationships between the Windsor and Horton groups. A considerable amount of time was spent mapping stratigraphic boundaries and structural relationships within the Horton Group. In the project area, it is possible to subdivide the Horton Group into the Horton Bluff and Cheverie formations. Murphy and Rice (1998) have proposed different subdivisions of the Horton Group in the study area and formally proposed new formation names. Although we recognize the value of Murphy and Rice's work, we have chosen to retain the lithostratighraphic subdivisions and terminology that correspond to the Horton Group type section.

[1]Funded by Natural Resources Canada and the Nova Scotia Department of Natural Resources under the Targeted Geoscience Initiative Project (Phase 2): Geological Mapping and Resource Evaluation in Central Nova Scotia
[2]Natural Resources Canada, PO Box 1006, Dartmouth, NS B2Y 4A2

Naylor, R. D., Brisco, D. C., Fisher, B. E., Giles, P. S., Goodwin, T. A. and Kontak, D. J. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 69-72.

A full discussion of the Carboniferous stratigraphy and structure in the project area is beyond the scope of this report. Details about the structure, lithostratigraphy and palynological analysis can be found on the new 1:50 000 scale maps of NTS areas 11E/06 and 11E/07 that are being generated as part of this project. These maps will be available in 2005.

Small mafic and felsic intrusives are found locally within the project area. Contact relationships between these intrusives and the surrounding Carboniferous strata have never been closley examined. Our fieldwork shows that in some instances it is possible to demonstrate that mafic units intrude Lower and Upper Carboniferous strata. Through the use of airborne magnetic data we were also able to more accurately define the size and location of the intrusive units. Further information on intrusive bodies in the map area is found in O'Reilly (this volume, p. 73-92).

The project has provided funding to digitize and compile a large number of bedrock maps into ArcView® format. These include:

- GSC published and open file maps 1058a, 1215a, 3757, 3535, and 3703;
- twenty-one previously unpublished maps which formed part of the Nova Scotia Department of Mines St. Marys River Basin Project (see location, Fig. 1) undertaken from 1968-1971;
- four previously unpublished 1:5 000 scale maps illustrating the work undertaken as part of a NATMAP project (see location, Fig. 1) in the St. Marys Basin by Brendan Murphy and Randy Rice from 1993-94. These maps will be released as Nova Scotia Department of Natural Resources Open File Maps;
- new 1:50 000 scale maps of NTS areas 11E/06 and 11E/07, created using new mapping carried out for this project and compiled data from previous workers; and
- thirteen new 1:10 000 scale maps detailing the Upper Carboniferous strata adjacent to the Cobequid Fault from Londonderry to Kemptown.

Mineral Deposit Research

Work during the past year as part of the TGI-2 program included logging relevant drill core from the Copper Lake and Mt. Thom districts (see Fig. 1) in order to ascertain the nature of mineralization and the extent of wall rock alteration in these settings. Core logging and associated field studies indicate both areas are underlain by extensive haloes of carbonate (calcite, mixed Fe-Mg carbonates) and alklai (i.e. albite) metasomatism with associated introduction of base and precious metals (Au) as sulphides. Preliminary petrographic and detailed mineralogical studies indicate that enrichment of apatite, rutile, xenotime, monazite and zircon also occurs, part of the alteration assemblage. Thus, there was also introduction of P, Ti, Zr, and light rare earth elements (LREE) as part of the hydrothermal mineralizing event. Hydrothermal monazite and zircon are amenable to direct radiometric dating and this work is underway; thus, the age of the alteration/mineralization event can be ascertained. Preliminary compilation of results of C and O isotopic data and trace element geochemistry for the two areas and the Londonderry district, a former iron-producing area to the west, suggests that there may be a genetic connection among these districts. Ongoing work and data collection include additional petrography, whole-rock and mineral chemistry, mineral paragenesis and geochronology. These data will be integrated into models for mineralization in the study areas.

Regional Surficial Geochemistry

During the summer of 2004 a total of 59 regional A-horizon humus, 59 B-horizon soil and 59 C-horizon till samples were collected from north-south transects across NTS map areas 11E/06, 11E/07, 11E/08 and parts of 11E/05 and 11E/12. The samples were collected in order to characterize the geochemical response of each sample medium, particularly where it is associated with the Cobequid-Chedibucto Fault Zone (Fig. 1). The samples are being analyzed using multi-element ICP-MS analysis by ACME Analytical Laboratories Limited of Vancouver, British Columbia. Analytical results are pending. A more detailed overview of this work is provided by Goodwin (this volume, p. 35-38).

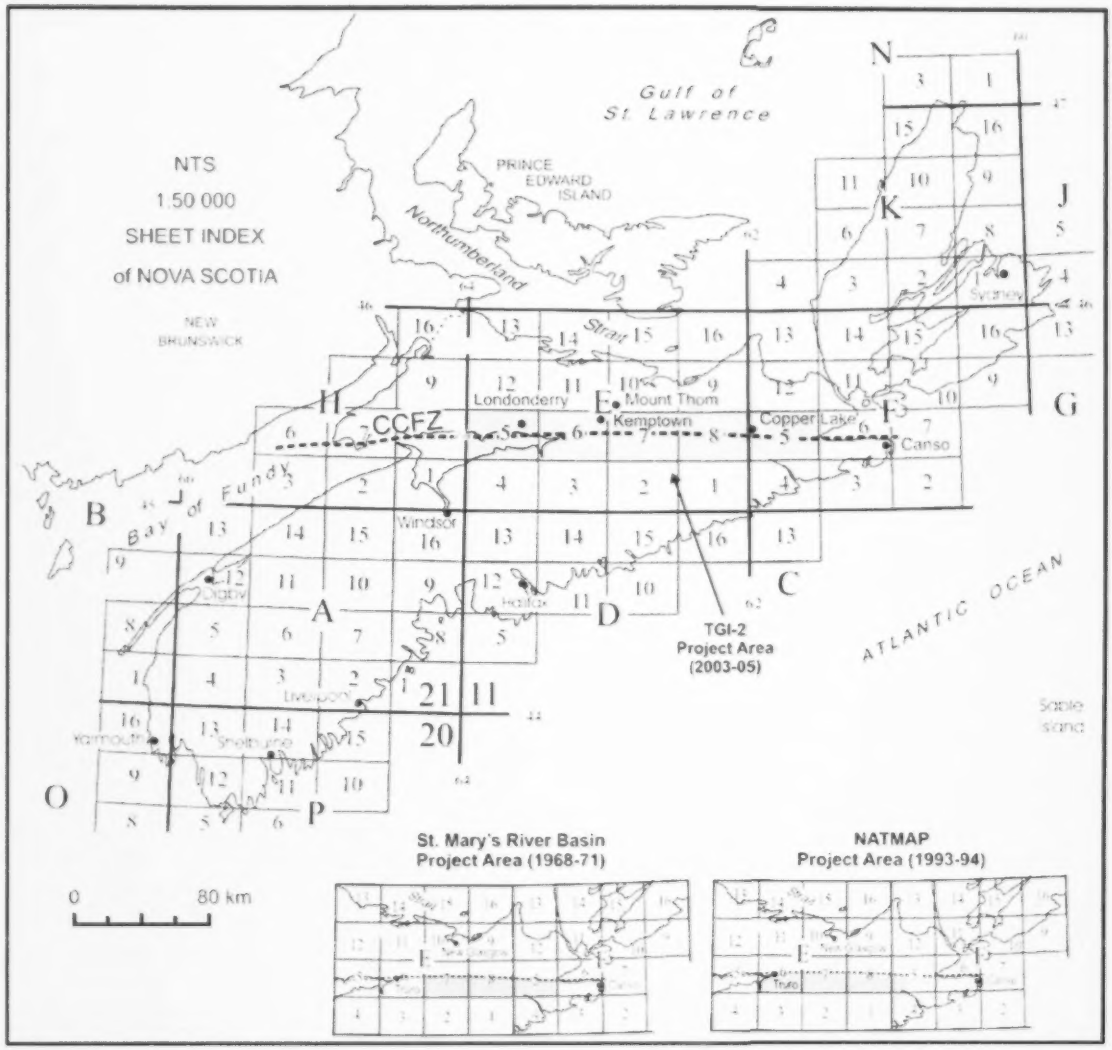

Figure 1. National Topographic System (NTS) index map of Nova Scotia showing locations of the TGI-2 and previous project areas. CCFZ = Cobequid-Chedabucto Fault Zone.

Geophysical Data

Some re-processing of historical seismic data was undertaken in 2004. The 1990 survey shot by Curragh Resources Ltd. in the Debert-Kemptown Coalfield was selected as a good candidate for reprocessing. Unfortunately, the results were not encouraging. No significant improvement in quality was achieved. As a result further reprocessing of seismic data was suspended.

In contrast, new work on magnetic and gravity data has produced some very useful results. During 2003 we prepared regional geophysical maps for the entire project area. These maps included: aeromagnetic (total field, calculated first and second vertical derivative) maps, Bouguer gravity maps, residual Bouguer gravity maps, and VLF-EM line and ortho total field maps (local coverage only). These data are available as part of a series of 1:2 500 000 and 1:50 00 scale maps that cover most of northern mainland Nova Scotia.

During 2004 new high-resolution airborne magnetic survey data were generously made available by Avalon Ventures Ltd., Monster Copper Corporation, and Wallbridge Mining Company. Collectively the surveys covered most of the northern half of NTS 11E/07 and a small area of northwestern NTS 11E/06. We have used the data to create enhanced map images and 2½-D models to study distribution of mafic intrusions. The enhanced map images have significantly improved our understanding of the structural geology and Carboniferous stratigraphy. Similarly, modelling of mafic intrusives has provided very useful information about the location and depth of these bodies. A final report on this work will be released in August 2005.

Radiometric data have also provided some useful information for understanding the geology in the TGI-2 project area. The Radiation Geophysics Section (Mineral Deposits and Applied Geophysics Subdivision) of the Geological Survey of Canada has completed province-wide radiometric surveys at 1 km line spacing. Digital radiometric data were acquired by the Nova Scotia Department of Natural Resources and processed for this project to generate colour/contoured shaded relief map images. Although our main interest was the radiometric coverage for the TGI-2 project area we processed data and created images for the entire province. This work will be available in 2005.

Future Work

All the products that had been planned for delivery as part of the Nova Scotia component of the TGI-2 program are published or in advanced stages of editing. The large amount of data generated by the project will be used to publish additional reports during 2005-06. These will include papers on the age of magmatic and mineralizing events in the Cobequid-Chedabucto Fault Zone and mineral paragenesis and alteration at Mount Thom and Copper Lake. Reports will also be prepared on the sedimentology, stratigraphy and depositional setting of late Carboniferous strata adjacent to the Cobequid Fault.

References

Murphy J. B. and Rice, J. R. 1998: Stratigraphy and depositional environment of the Horton Group in the St. Marys Basin, central mainland Nova Scotia; Atlantic Geology, v. 34 p. 1-25.

Naylor, R. D., Fisher, B. E., Giles, P. S., Goodwin, T. A. and Kontak, D. J. 2004: Progress report on a new mapping and resource evaluation program for central Nova Scotia; *in* Mineral Resource Branch Report of Activities 2003; Nova Scotia Department of Natural Resources, Report 2004-1, p. 87-91.

Mafic and Felsic Intrusions in Carboniferous Rocks of Central Nova Scotia[1]

G. A. O'Reilly

Introduction

Central Nova Scotia, including NTS map areas 11E/06, 11E/07 and the southern portion of 11E/10 and 11E/11, is underlain predominantly by sedimentary rocks of Carboniferous age (Fig. 1). Several workers have indicated that small intrusion of mafic and felsic composition are hosted by these rocks but little attempt has ever been made to determine their age and contact relations relative to their hosts. It is known that the plutons show an association, spatially at least, with regional and secondary-scale faults belonging to the Cobequid-Chedabucto Fault Zone (CCFZ) but whether or not the plutons actually intrude their hosts or are pre-Carboniferous in age and simply brought into their current position by faulting is not known.

There is an important economic implication to answering this question of age. Northern Nova Scotia and, in particular, the CCFZ and Carboniferous units it deforms, shows many of the features typical of a terrain hosting the much sought-after iron oxide-copper-gold (IOCG) type of mineral deposits. Foremost among these features are the presence of several small examples of these deposits (e.g. Mt. Thom Cu-Co-Au prospect and Copper Lake Cu-Fe-Au mine) and an abundance of deposits of iron oxide, ankerite and siderite, many of which were mined for iron in the 19th Century (e.g. Londonderry, Bridgeville). Currently, the CCFZ is undergoing exploration by several companies for IOCG deposits, and the ability to define if any of these intrusions played a role in the formation of these deposits will aid in further refinement of a metallogenetic model for IOCG deposits in Nova Scotia. With this aim in mind, several of the mafic and felsic intrusions were examined and sampled in 2005 as part of the Targeted Geoscience Initiative, Phase 2 (TGI-2), a joint federal-provincial agreement to help stimulate petroleum and mineral exploration in central Nova Scotia. The mapping had two components:

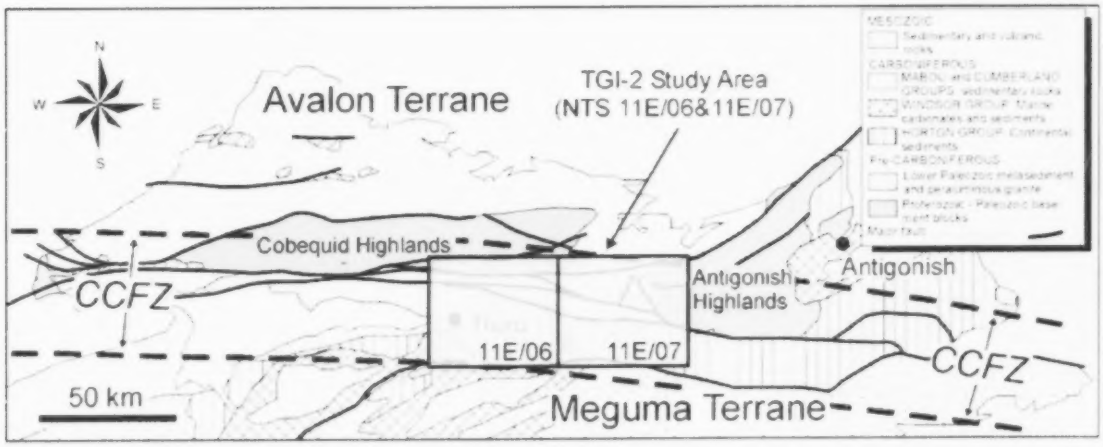

Figure 1. Geology of northern Nova Scotia along the Cobequid-Chedabucto Fault Zone (CCFZ) showing location of the TGI-2 study area.

[1]Funded by Natural Resources Canada and the Nova Scotia Department of Natural Resources under the Targeted Geoscience Initiative, Phase 2 (TGI-2)

O'Reilly, G. A. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 73-92.

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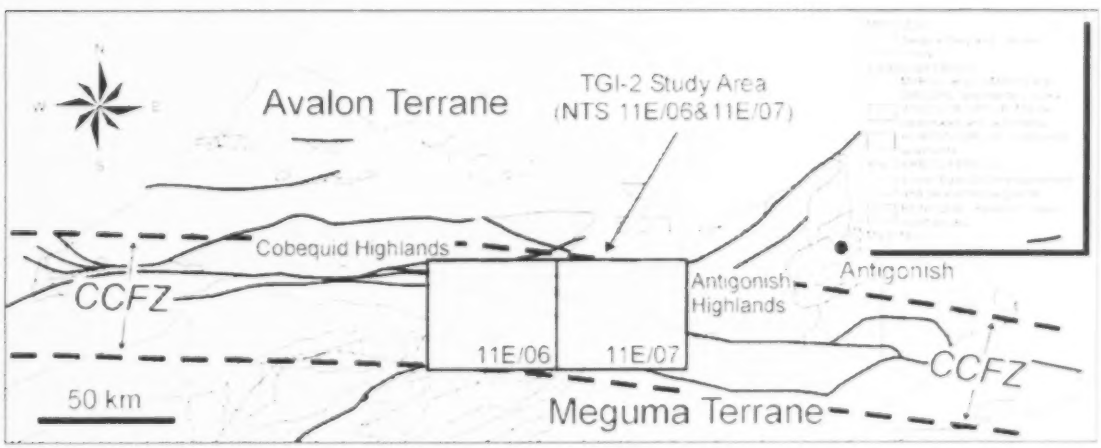

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O'Reilly, G. A. 2005 *in* Mineral Resources Branch, Report of Activities 2004. Nova Scotia Department of Natural Resources Report ME 2005-1, p. 73-92

(1) definition of field relations described herein, and (2) sampling for absolute age dating, carried out jointly with D. J. Kontak. A report on the results of age dating is introduced by Naylor *et al.* (2005) and will be presented in more detail when the analytical work is completed.

Geology of Central Nova Scotia

The Cobequid-Chedabucto Fault Zone and the Evolution of Carboniferous Basins

From an economic standpoint, the Carboniferous sedimentary and marine strata of Nova Scotia are of the greatest importance, as these units have provided most of the industrial and metallic mineral resources of the province since European settlement some four centuries ago. These include the vast coal deposits for which the province is famous, as well as huge resources of gypsum, limestone and building stone. As well, the Carboniferous units are host to many significant deposits of base metals, Ba, Cu, and the once economically significant iron-oxide vein deposits, of which the Londonderry Iron District is most notable.

The CCFZ is perhaps the single most important geological feature in the province and is the main governing factor behind the evolution of the Carboniferous basins. This system of regional, crustal scale, transpressional, strike-slip and thrust fault structures governed formation of most of the basins into which sediments were deposited during the latter stages of the middle Paleozoic Acadian Orogeny. The faults also served as channelways allowing the rise of mantle-derived plutons of gabbro-diorite and related A-type granitic plutons. Attending the plutons was a very widespread and pervasive hydrothermal alteration event, characterized by K-Na-Fe-Si-CO_2 alteration. More importantly, the fault structures and associated hydrothermal alteration are associated with formation of many of the province's mineral deposits. Carbonate-hosted base metal and barite deposits at Walton, Gays River, Smithfield, Jubilee and Brookfield all had a significant component of structural control in their formation. Likewise several interesting deposits of iron-oxide-copper-gold (IOCG) and related iron-oxide deposits, such as were mined in the former iron-mining districts, all have a direct structural association to the CCFZ.

Pre-Carboniferous Basement Rocks

Avalon Terrane

The Carboniferous rocks of northern Nova Scotia represent basin-fill deposits of sediment adjacent to and along the flanks of highland blocks of Precambrian and lower Paleozoic crystalline basement. The highland blocks developed by dextral, strike-slip and thrust faulting along sutures of the CCFZ (Pe-Piper *et al.*, 2004). Formation of the CCFZ began in the lower Paleozoic but, by far, most movements occurred related to the docking of the Avalon and Meguma terranes during the Devonian Acadian Orogeny. The Cobequid Highlands underlie the western end of the CCFZ and is a horst structure consisting of arc volcanics, plutonic rocks and associated lower Paleozoic sedimentary rocks (Pe-Piper and Piper, 2002). Part and parcel of the highland formation was emplacement of a voluminous series of gabbroic and A-type granitic magmas and their extrusive equivalents during the very latest Devonian and into the early Carboniferous (Pe-Piper *et al.*, 2004). Movement along the faults continued episodically into the late Carboniferous, as did intrusion of volumetrically lesser amounts of mafic magma and attendant hydrothermal alteration.

The Antigonish Highlands are geologically similar to the Cobequid Highlands except that they are dominated by lower Paleozoic volcanic and turbidite sequencess intruded by granodioritic and granitic plutons of intermediate composition (Benson, 1974a; Murphy *et al.*, 1991). Plutons and plugs of mafic composition are also present throughout the Antigonish Highlands, especially close to the CCFZ (Benson, 1974b).

Meguma Terrane

The CCFZ marks the tectonic boundary between the Avalon Terrane to the north and the Meguma Terrane to the south (Fig. 1). The Meguma Terrane consists predominantly of the lower Paleozoic

turbiditic metasediments of the Cambro-Ordovician Meguma Group. The Meguma Group consists of the metawacke-dominated Goldenville Formation and conformably overlying slate-dominated Halifax Formation.

A cogenetic suite of peraluminous granitic rocks of the late Devonian age intrude the Meguma Group. These granites range in composition from tonalite to highly evolved leucogranite but, volumetrically, granodiorite is the most important phase. The Meguma Terrane, although not a highland of the same dimensions as the Cobequid and Antigonish highlands, still served as a basement providing sediment for transport and infilling of the Carboniferous basins after the Acadian Orogeny.

The Carboniferous Succession

Horton Group

The Carboniferous sequence in central Nova Scotia began with deposition of large amounts of clastic continental alluvium in graben and half-graben basins adjacent to sutures of the CCFZ. These sediments have been assigned to the Horton Group, consisting mostly of coarse sandstone, siltstone and conglomerate (Benson, 1967a).

The Horton Group type section was defined by Bell (1929) from the Horton Bluff area near Windsor, where it consists of the Horton Bluff Formation and conformably overlying Cheverie Formation. This nomenclature has been retained for the Horton Group in the TGI-2 study area (Naylor *et al.*, 2005). Horton Group rocks are mostly confined to the St. Mary's Graben, which underlies the southern portion of NTS map areas 11E/06 and 11E/07, and is a rectangular structure 130 km long by 15 km wide that is almost entirely bounded by major splay faults of the CCFZ. Within the graben, Benson (1967a, 1974a) subdivided the Horton Group into three units he felt were equivalent to the Craignish, Strathlorne and Ainslie formations, defined on Cape Breton. In general, the Craignish Formation is equivalent to the Horton Bluff Formation, and the Strathlorne and Ainslie Formations to the Cheverie Formation.

Mapping as part of the TGI-2 project has shown that within the eastern half of the graben, and especially underlying the area south of Lorne, the rocks belong to a middle member of the Horton Bluff Formation. They consist of grey to dark grey shale and siltstone, alternating with thin bands of grey to green mudstones. Conformably overlying these rocks is an upper member of the Horton Bluff Formation which consists of light- to medium-grey quartz arenite beds, interbedded with grey shale, mudstone, nodular dolostone and minor conglomerate. Overlying the Horton Bluff Formation are grey to green sandstones of the Cheverie Formation with local conglomerate interbedded with maroon and grey mudstone. The fossil assemblage within the Horton Group indicates it is Tournaisian in age (earliest Carboniferous stage) and deposition was continental in origin. The uppermost Horton Group strata are latest Tournaisian (Bell, 1929).

Windsor Group

The continental sediments of the Horton Group are overlain by a sequence of marine sediments with interbedded evaporite sequences known as the Windsor Group. Incursions of continental sediments are also known in the Windsor but are minor. Although the contact of the Horton and Windsor groups appears to be conformable, fossil evidence suggests a depositional hiatus between the two. The uppermost Horton Group rocks have Tornaisian fossil assemblages while the lowermost Windsor Group beds are mid-Viséan (Calder, 1998).

Most of the Windsor Group rocks in the TGI-2 study area are confined to the Eureka area (NTS 11E/07). Giles (1982) mapped these rocks and applied local names to formations found therein. However, for the purposes of keeping things simple in this report, the more established names assigned to these same Windsor Group units in the Shubenacadie and Musquodoboit Carboniferous basins (Giles *et al.*, 1979) are used here.

The oldest Windsor Group rocks known in the study area belong to the Gays River Formation which consist of a carbonate buildup (bank) of partly laminated limestone and lesser dolostone best developed in areas where the Windsor Group directly onlaps pre-Carboniferous basement. The unit is usually thinly bedded but locally contains thick beds. The Gays River Formation is the lateral equivalent to the finely laminated limestone of the

Macumber Formation, which marks the beginning of the Windsor Group succession at many other locales in the province. At Bridgeville, these Gays River Formation rocks, and their immediately underlying pre-Carboniferous crystalline basement rocks, host most of the deposits of hematite previously mined at the Bridgeville Iron Mines (Wright, 1975).

Conformably overlying the Gays River Formation are thick units of gypsum and anhydrite of the Carroll's Corner Formation, termed the Bridgeville Formation by Giles (1982). The Carroll's Corner Formation is a thick succession of poorly stratified anhydrite and gypsum with minor, irregular beds of limestone and dolostone. In the Eureka basin, rocks of the Carroll's Corner Formation are found immediately above the Gays River Formation along the eastern margin of the basin and its contact with pre-Carboniferous rocks of the Antigonish Highlands.

Disconformably above the Carroll's Corner Formation is the MacDonald Road Formation or Forbes Lake Formation of Giles (1982). The MacDonald Road Formation consists predominantly of maroon to pale greyish-red shale, mudstone and paraconglomerate. Minor limestone beds are also present. Cyclic repetition of these rocks is characteristic.

Conformably overlying the MacDonald Road Formation are the maroon to reddish-brown mudstone, fine-grained sandstone and intercalated sheets of limestone and grey, fossiliferous mudstone and shale of the Green Oaks Formation. Some beds of anhydrite and gypsum are present. Giles (1982) refers to these rocks as the Churchville Formation.

Mabou Group

The Mabou Group was described and introduced as a replacement for the Canso Group by Belt (1964, 1965). Many early maps of central Nova Scotia use the term Canso Group (Benson, 1967; Donohoe and Wallace, 1982). The Mabou Group consists of a succession of fine-grained, red and grey, fluvial and lacustrine strata which overlie the Windsor Group. Mabou Group rocks underlie substantial portions of NTS map areas 11E/06 and 11E/07. Although it is poorly established, the Mabou Group is considered to be a lateral equivalent to the Londonderry Formation, although the latter only occurs as fault bounded blocks along major splays of the CCFZ. The relationship between the Mabou Group and the Londonderry Formation is important considering that the substantial hematite and ankerite vein systems that constitute the Londonderry iron deposits are hosted by Londonderry Formation rocks, so it is unfortunate that a better defined relationship has not been established.

Cumberland Group

The upper Carboniferous or, coal-bearing, rocks in Nova Scotia have been referred to under several group names including Riversdale, Morien, Stellarton and Pictou. Ryan *et al.* (1991) proposed an expanded definition of the Cumberland Group to include all the typically heterogeneous sandstone, mudrock and conglomerate stratigraphically above the Mabou Group. In the TGI-2 project area the Cumberland Group consists of the Boss Point, Parrsboro, Totten Brook, Chiganois River, Cross Road and Debert formations. In the area studied for this report only rocks of the Boss Point, Parrsboro, Chiganois and Cross Road formations are found.

Plutonic Rocks Hosted by Carboniferous Strata

Mafic Plutons

A review of the available geology maps, literature and mineral exploration assessment files (Fletcher, 1892, 1902a, 1902b, 1902c, 1902d; Benson, 1967b, 1974b; Mersereau, 1974; Giles, 1982; Black, 1995, Rankin, 1997) shows that the Carboniferous rocks along the CCFZ in central Nova Scotia host numerous, small igneous intrusions and dykes. Most of the intrusions are mafic in composition and several were examined in 2004 as part of the TGI-2 project. A description of each site visited follows.

Moiche Hill Gabbro and Carbonate Breccia Complex

Fletcher (1892, p. 150P) and Benson (1967a, p. 36) make reference to a mixed sequence of gabbro and limestone at Moiche Hill (referred to as Robert

Gordon's Hill by Fletcher) near Glengarry Station (Fig. 2). The geology map of this area by Fletcher (1902a) shows a small quarry on the site where lime was extracted by the local farmers for agricultural purposes. It is clear from the brief description of Fletcher (1892) that he considered the carbonate exposed here to be layers of limestone enveloped in reddish "trap". A lifetime resident of the area confirmed that early settlers used to periodically visit this site, where they would fill the pit with hardwood then blow large blocks of the mixed limestone and gabbro into it and start a fire. After the blocks were cooked they would crush them, mix them with the ash, and spread the mixture on their fields.

Traverses across Moiche Hill, and along Middle River of Pictou where it follows the base of the hill, quickly showed that much of the hill is underlain by a fragmental gabbroic pluton (Fig. 2). Outcrops of dark grey to purplish gabbro are exposed in the old quarry and along the crest of the hill west from the quarry to the Glengarry Station Road. In addition, the hillside itself is draped by a substantial talus consisting of more than 80% gabbro boulders. Outcrops and rubble crop of the gabbro found along the road leading north toward Marshdale indicate that the complex extends at least that far to the northeast. Toward the west, one probable outcrop of gabbro occurs along the road leading north from Glengarry Station, a short distance north of the bridge over Middle River of Pictou (Fig. 2).

The area surrounding the Moiche Hill gabbro is underlain by maroon to light grey sandstone and siltstone of the Carboniferous Mabou Group. Outcrops of these sediments are found along the

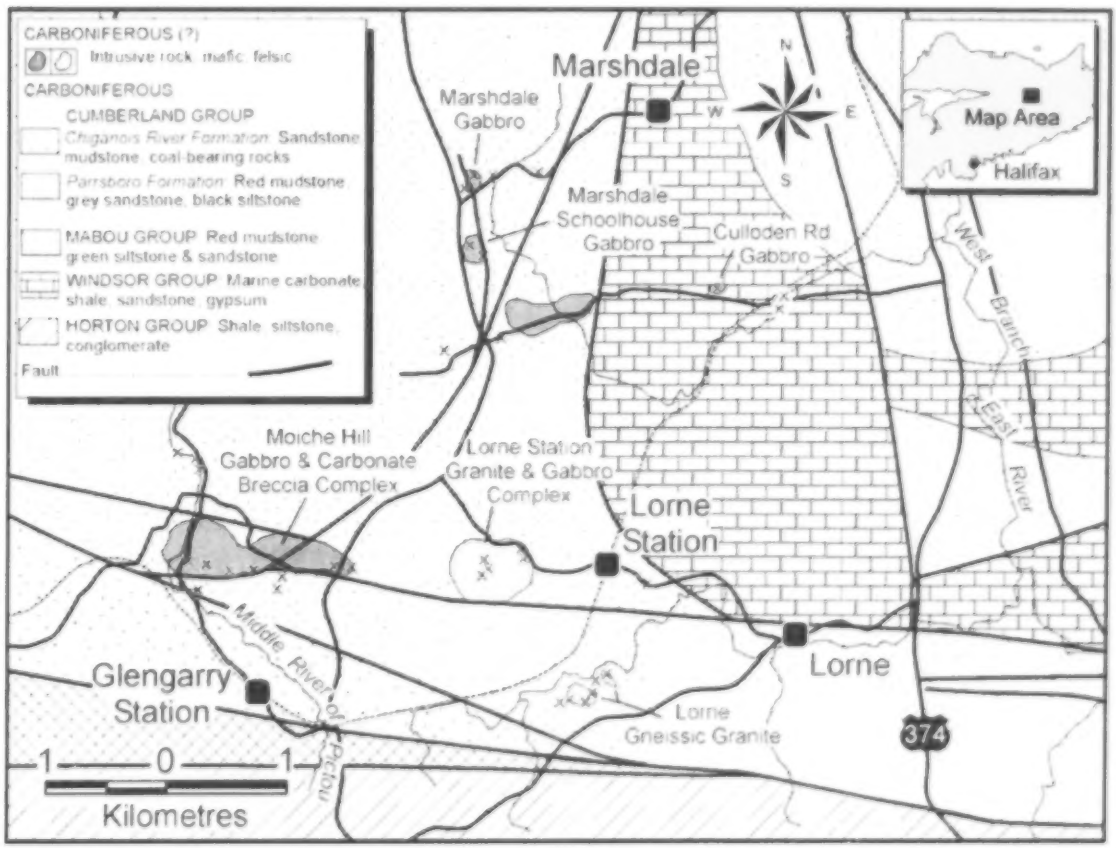

Figure 2. Geology of the Lorne-Marshdale area, southern Pictou County, showing igneous intrusions examined as part of the TGI-2 Project.

Middle River of Pictou and along several roads that encircle the hill. In addition, outcrops of Mabou Group redbeds were found during traverses of the southeastern face of the hill, immediately north of the now abandoned site of the old Glengarry railway station.

It is clear from the gabbro outcrops, and from the abundant gabbro boulders that drape the hill, that the intrusion is mostly brecciated. This especially holds for the pluton's southern contact. The gabbro is fine- to medium-grained and grey to greenish-grey in colour. In places it is porphyritic with fine laths of plagioclase. Evidence of brecciation is ubiquitous, as is the occurrence of minor amounts of fracture-controlled specularite. Outcrops and large boulders are mildly magnetic. The gabbro exposed in the 50 m long, by 3-5 m deep, pioneer era quarry is also brecciated. The distribution and frequency of blocks of brecciated sediment in the southern part of the quarry suggests that area may be underlain by Mabou Group rocks, although they are not exposed.

The 2-3 m high outcrop faces along the eastern edge of the quarry expose totally recrystallized carbonate (marble) interlayered with lenses of brecciated gabbro and fragments of broken red sediment. A planar layering obvious within the carbonate trends 074° Az, dipping 84° south, and appears to be extensional in origin. In addition, carbonate-filled extensional fractures are present in many of the larger breccia fragments of both gabbro and sediment.

There is no evidence to suggest that the carbonate exposed in the quarry is a recrystallized version of what was originally Carboniferous limestone. The distribution of the carbonate in the pit, its intimate interlayering with gabbro, and its totally recrystallized (marble) condition all strongly suggest that the carbonate is hydrothermal in origin and localized along the brecciated contact of the gabbro intrusion with the Mabou Group country rock. The alignment of brecciated outcrops of gabbro and sediment along the southern and southeastern contact of the intrusion indicates that a northeast-trending fault passes through this area and continues north toward Marshdale (Fig. 2).

A sample from of the Moiche Hill gabbro has been submitted for Ar^{40}/Ar^{39} dating.

Marshdale and Marshdale Schoolhouse Gabbros

Two small intrusions of dark green, medium- to coarse-grained gabbro are found at Marshdale, Pictou County (Fig. 2). One, named here the Marshdale gabbro, is exposed in an aggregate quarry opened in the mid-1960s to provide construction material for the Harvey Venoit Causeway joining New Glasgow and Pictou. The other, now named the Marshdale Schoolhouse gabbro, outcrops as a small knoll behind the site of the former Marshdale schoolhouse, a few hundred metres south on the road to Glengarry from the Marshdale intersection (Fig. 2). Fletcher (1892, p. 150P; 1902) reports the area behind the school had several prospect pits dug in search of specularite occurring within gabbro. Benson (1967b), on his geology map of the area, indicates a small dyke of gabbro at the site of the Marshdale Schoolhouse gabbro but does not show the existence of the Marshdale gabbro intrusion immediately to the north.

It is possible the two gabbros are actually one pluton but the existing outcrop distribution will not allow a firm answer on this. Second derivative aeromagnetic data (Geological Survey of Canada) over this area shows the presence of two low-amplitude magnetic anomalies, corresponding with each area of gabbro outcrop. This suggests that two separate plutons exist, although they still may be connected at depth.

The distribution of outcrops at the Marsdale quarry indicates that the pluton has a minimum size of 90 m long by 70 m wide. A prominent 10 m high spire of gabbro remains at the north end of the quarry and represents the original height of the outcrop knoll prior to quarry construction. Much of the gabbro occurs as a dark green, coarse-grained, hypidiomorphic, granular textured rock consisting of hornblende, pyroxene and plagioclase. Minor amounts of sphene and hematite are present. Lighter coloured, metre scale patches occur within the gabbro and may represent portions of more differentiated gabbro or metasomatic alteration zones. These light coloured patches are more plagioclase-rich and commonly contain disseminations of specularite, pyrite and lesser chalcopyrite.

Considerable loose gabbro rubble lies about the pit and among the rubble occur large boulders showing an intrusive contact of the gabbro with an odd textured, fine-grained, light-to dark-green, layered rock (Fig. 3). Geology maps (Benson, 1967b; Giles, 1982) show the Marshdale area to be underlain by red to green siltstone and sandstone of the Mabou Group. An outcrop of typical Mabou Group, very friable red siltstone is found on the north side of the Marshdale-Hopewell Road about 200 m east of the quarry. On the west side of the Marshdale-Glengarry Road, immediately opposite the Marshdale intersection, which is 100 m west of the quarry, rubble crop of mixed grey to red siltstone and mudstone is found (Fig. 2). On entering the quarry, however, a bank along the left-hand side of the road that skirts the west edge of the pond at the centre of the pit exposes several outcrops of the odd textured rock mentioned above. The rock is light green to dark green, with a pronounced layering and very fine grain size. At first glance it resembles rhyolite, but the presence of numerous light coloured, spherical alteration blebs, encircled by mottled, calc-silicate and porcelain alteration, suggests it is actually a highly altered rock developed by heat and escaping fluids during intrusion of the gabbro. The rock occurs in the contact zone of the gabbro and the ubiquitous presence of breccia indicates the contact is highly faulted. The overall composition and texture of the thermally and metsomatically altered contact rock is markedly different than the much softer and more friable Mabou Group red siltstone and mudstone found a couple of hundred metres to the east. Outcrops of interbedded green and grey, laminated siltstones found to the south along the west end of the Culloden Road (Fig. 2), however, may easily represent a non-altered protolith of the contact rock.

Figure 3. Photograph of altered and deformed contact rock from the Marshdale gabbro intrusion.

Veins of white calcite, some with quartz, intrude the gabbro and many of these carry well formed crystals of pyrite and chalcopyrite. In fact, euhedral crystals of chalcopyrite are present and this marks the only location in the province where I have observed this mineral in euhedral form. Specularite also occurs with the sulphides in some of these veins, and also separately, sometimes in significant amounts speckled throughout the matrix of the brecciated contact rock.

A sample of the Marshdale gabbro has been submitted for Ar^{40}/Ar^{39} dating.

The Marshdale Schoolhouse gabbro occurs as a small knoll in the woods behind the location of what was once the Marshdale School (Fletcher, 1902a; Fig. 2). The school was located on the east side of the Marshdale-Glengarry Road, 380 m south toward Glengarry from the Marshdale intersection. The school was lost in a fire in 1936 and a portion of what remained of the structure was incorporated into one of the nearby homes. A small pond is found in the woods immediately to the east of the road and pits, trenches and outcrops of gabbro are found to the east and north of the pond. Fletcher (1892) indicated that the pits were dug on the gabbro in quest of iron from the large patches of specularite that occur in the rock. An examination of the property shows that several small pits and trenches are present, and it also appears as if the pond itself is man-made and the result of nature reclaiming what was once a pit related to the past prospecting. Loose gabbro litters the area and much of it is mineralized with specularite. The distribution of pits and outcrop suggests that the gabbro intrusion is elongate toward the north with a minimum size of 110 m by 60 m. The second derivative aeromagnetic data (Geological Survey of Canada) for this area suggest the pluton is more circular and slightly larger.

The Marshdale School gabbro is similar in composition and texture to the pluton exposed in the Marshdale quarry. Most of the pluton is coarse grained, but there is an apparent fining of the grain size toward the road (west) suggesting that the contact is being approached in that direction. Unfortunately, the country rock to the pluton is not exposed and none was noted in the abundant loose rubble that litters the prospect. This pluton is thought to be hosted by Mabou Group sediments but no inferences on the contact relations of these rocks with this particular gabbro intrusion can be made.

As far as tonnage and amount of massive iron-oxide are concerned, there is not a substantial abundance of specularite within the gabbro, but there are some fairly spectacular specimens of the mineral to be found. Gabbro containing large patches and blades of specularite 3-4 cm in length are common. Most of the specularite occurs within veins and along fractures, but some occurs as patches and segregations within the gabbro suggesting it crystallized by way of direct metasomatic alteration processes within the gabbro as opposed to post-crystallization precipitation along fractures and fault planes.

Culloden Road Gabbro

A small intrusion of gabbro outcrops in a farmer's field on the north side of the Culloden Road south of Marshdale (Fig. 2). The Culloden Road leads west from Highway #374 about halfway between the village of Hopewell and the community of Lorne. The field is about 2 km west of the highway, on the north side of the road, a few hundred metres west of the railway crossing. The gabbro consists of a single, prominent outcrop surrounded by trees that were left for livestock to shelter from the sun. The outcrop measures 5 m by 5 m, and is surrounded by abundant gabbro rubble, most of which has angular, sharp edges (Fig. 4). The rock is medium grey and, for the most part, is shot through with a stockwork of cream coloured quartz-calcite veins. The veins appear to be filling closely spaced extensional fractures and tension gashes.

The gabbro appears to be highly silicified and carbonitized. The veins occupy a variety of orientations but most trend 073° Az and are vertical to steeply dipping toward the south. The outcrop also contains several flat-lying shear zones which crenulate and offset the quartz-calcite stockworks. Pyrite, pyrrhotite, specularite and minor chalcopyrite occur within the quartz-calcite veins and, to a lesser extent, as disseminations throughout the gabbro.

No country rock outcrops occur near the gabbro so direct inferences cannot be drawn as to the contact relations. This area is mapped by Giles (1982) as being underlain by maroon to reddish-

Figure 4. Outcrop of gabbro intruded by extensional calcite-quartz veins on the Culloden Road.

brown mudstone and sandstone of the Green Oaks Formation (called Churchville Formation by Giles), which occupies the upper part of the Carboniferous Windsor Group. Boulders of these rocks abound in the road gutters and rock piles throughout the Culloden Road area and an outcrop of very friable, red mudstone is exposed on Cameron Brook where it meets Culloden Road about 500 m east of the gabbro.

It is interesting to note that Fletcher (1892) makes frequent mention of clusters of gabbro boulders, often highly veined with calcite and quartz, being found along the trace of the Chedabucto Fault from Glengarry east to Sunnybrae. Many of these boulder clusters are found along the north scarp of the St. Marys Graben, an area underlain by Carboniferous Horton Group rocks. Some of the clusters, however, occur in areas underlain by rocks belonging to the younger Windsor and Mabou groups. The Culloden gabbro would be one such occurrence. A sample from this outcrop has been submitted for Ar^{40}/Ar^{39} dating.

Centredale Gabbro Intrusions

Three gabbro plugs are found in Mabou Group rocks in the Centredale-Elgin area east of Lorne, Pictou County (Fig. 5). Outcrops of the Elgin and Centredale plugs are indicated as single diabase outcrops on Giles (1982). Benson (1967b) indicates a diabase outcrop at Centredale but not the one at Elgin. The largest, and easternmost of the three plugs, is found between Centredale and Archibalds Brook but it has no known outcrops. Its existence is inferred by the presence of a strong magnetic anomaly that underlies the area. Similar, but lower amplitude, magnetic anomalies underlie the Centredale and Elgin plugs.

Benson (1967b) mapped the Centredale area as being underlain by Windsor Group sediments. Giles (1982), based on spore data, felt that the rocks south of the Centredale Fault actually belonged to the Mabou Group (Fig. 5). Any examination of the section between the Centredale Fault and the Chedabucto Fault, about a kilometre and a half to the south, will quickly reveal that these rocks are indeed highly faulted and several faults parallel to the main bounding faults also probably exist.

The westernmost of the three gabbro plugs outcrops along a stream that parallels the road leading from Elgin to Centredale (Fig. 5). Measuring from the Centredale intersection, drive 1 km west toward Elgin. At that point the stream is immediately north of the road. Walk upstream along the stream to where it swings to the north and about 50 m farther upstream is an outcrop of coarse grained, dark green gabbro on the west bank. This gabbro is similar in texture and composition to the gabbro exposed in the Marshdale quarry several kilometres to the northwest. Immediately to the west of the outcrop on the stream is a prominent west-trending knoll. A second gabbro outcrop is found about another 100 m west along this knoll. A considerable amount of gabbro float litters the stream and along the trend of the knoll, suggesting that gabbro underlies much of this area. How far it extends to the west is not known, but it is felt that the extent of the magnetic anomaly in the Geological Survey of Canada aeromagnetic survey over this area provides some idea, and this information was used in defining the size of the pluton in Figure 5.

Although the contact of the gabbro with the Mabou Group sediments is not exposed, about 20 m downstream from the gabbro outcrop on the

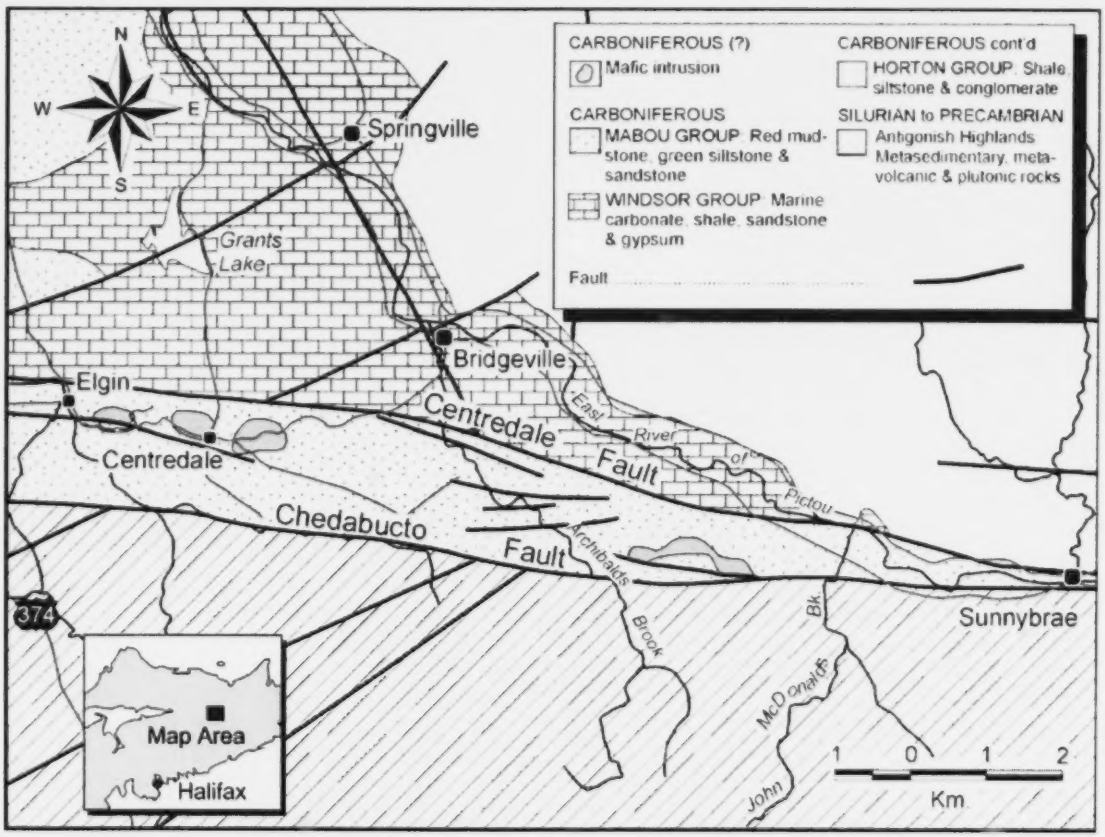

Figure 5. Geology of the Centredale-Sunnybrae area of Pictou County showing the location of gabbro intrusions examined in 2004.

brook is found an outcrop of highly deformed and thermally altered calcareous siltstone. This suggests, but does not prove conclusively, an intrusive relationship between the gabbro and the Mabou Group. The outcrop contains disseminated pyrite and is also intruded by veins of pinkish gypsum.

The gabbro at Centredale underlies the area northwest of the intersection of the Elgin and Grants Lake Roads (Fig. 5). A large outcrop of dark green, coarse-grained gabbro is exposed on the north bank of a brook about 40 m west from the Centredale intersection and on the north side of the road to Elgin. Texturally and compositionally, this gabbro is identical to the intrusion at Elgin and Marshdale. This intrusion is recorded as a single outcrop by Benson (1967b) and Giles (1982) who infer it may simply be a small dyke. However, the brook for at least 200 m west from the Centredale intersection consists almost entirely of gabbro boulders. As well, gabbro constitutes 70-90% of the float for 200-300 m northwest from the intersection which corresponds with a small topographic high in that area. The distribution of the gabbro float and the configuration of the magnetic anomaly in the aeromagnetic data in this area suggest that the gabbro plug is roughly circular with a diameter in the order of 200 m or more.

The contact of the gabbro with the surrounding Mabou Group sediments is not exposed, nor are there any Mabou Group outcrops close by. The only suggestion of an intrusive relationship are the presence of float of bleached and thermally altered sediment mixed with gabbro float on the periphery of the intrusion. Outward from the known area of

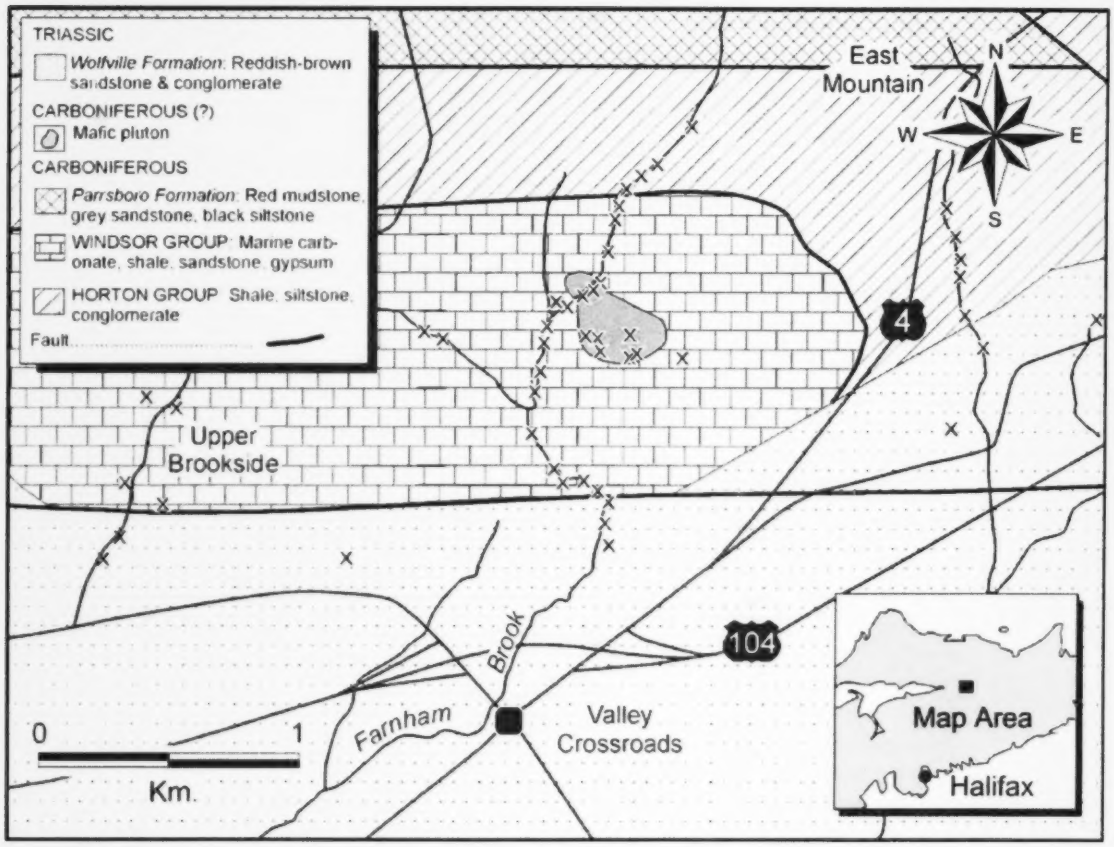

Figure 6. Geology map of the East Mountain area, north of Truro, showing the East Mountain gabbro intrusion

the intrusion, the frequency of this altered-sediment float decreases until there is only the red-maroon sandstone and siltstone typical of the Mabou Group.

A sample of the Centredale gabbro has been submitted for an Ar^{40}/Ar^{39} age determination.

The easternmost of the three Centredale gabbros is not known to outcrop. However, the magnitude of the magnetic anomaly over that area in the Geological Survey of Canada aeromagnetic surveys strongly suggests a gabbro intrusion is present (Fig. 5). The magnitude of the anomaly suggests the pluton will be similar to the two intrusions to the west at the Centredale intersection and near Elgin, but slightly larger.

East Mountain Gabbro

Two currently producing aggregate quarries have been developed in a gabbro intrusion on the southwest end of East Mountain (Fig. 6). Fletcher (1902c) indicates a mafic intrusion in this area on his geology map, and Donohoe and Wallace (1982) indicate two outcrops of diabase in the area immediately to the east of the present-day quarries. However, the previous mapping preceded construction of the quarries. Donohoe and Wallace (1982) also indicate the area surrounding the intrusion as being underlain by Horton Group sediments and a block of Windsor Group limestone underlies the area immediately to the west. They show a fault separating the two units. Mapping done as part of the TGI-2 project (Naylor *et al.*, 2005) shows that, in fact, the Windsor Group is more extensive and actually underlies much of the southwest end of East Mountain, including the area surrounding the gabbro. The extent of the gabbro intrusion provided in Figure 6 is based on outcrop as well as the footprint of a low amplitude magnetic anomaly in Geological Survey of Canada aeromagnetic data that cover this area.

The gabbro typically has a purple-grey colour and is texturally inhomogeneous. For the most part, the gabbro is fine- to medium-grained, with large portions that are massive and somewhat resemble volcanic rock. Several zones within the gabbro are porphyritic due to the presence of fine plagioclase laths. Throughout the quarries are found several pods consisting of an abundance of plagioclase and light coloured tremolite. These pods are gradational in the massive and porphyritic portions of the gabbro and are believed to be the result of metasomatic processes in the melt prior to crystallization. Veins of jasper and a reddish carbonate also intrude the gabbro.

The contact of the gabbro with the enclosing Windsor Group sediments is not exposed, but gabbro outcrops on Farnham Brook are found within a few metres of Windsor Group limestone outcrops (Fig. 6). The limestone outcrops show thermal upgrading to marble, the degree of which decreases away from the gabbro, indicating that an intrusive relationship is almost certain.

A sample of the East Mountain gabbro has been submitted for an Ar^{40}/Ar^{39} age determination.

Salmon River Gabbro

A gabbro dyke is exposed on the east bank of the Salmon River about 1 km north of where it joins with the Black River (Fig. 7). Fletcher (1892, p. 152P) was first to make mention of the dyke and the fact that the sedimentary country rock adjacent to it is considerably altered. He also noted the increased occurrence of veins of ankerite and specularite near the dyke. Fletcher (1902d) indicates the dyke on his map of this area, as do Donohoe and Wallace (1982). The latter interpret the gabbro as a lens-like body adjacent to the Riversdale Fault, which traverses this area.

The contact of the gabbro with the enclosing siltstone and sandstone of the Carboniferous Boss Point Formation is well exposed here (Fig. 8). There is strong evidence that an intrusive relationship exists. As was first noted by Fletcher (1892), there is considerable bleaching and annealing of the sedimentary country rock (Boss Point Formation) adjacent to the gabbro. This alteration extends into the sediment for 8-10 m away from the contact, and is also accompanied by minor brecciation in some areas and production of secondary specularite, ankerite and minor barite. Areas of more pronounced bleaching and alteration are also associated with increased magnetism. The contact trends 030° and dips 48° east. There is also a pronounced fining of the grain size within the gabbro toward the contact, which is suggestive of chilling. Within a few metres into the dyke, the grain size increases to a coarse size and remains so for the remainder of the exposed width of the

intrusion. Existing outcrops indicate that the gabbro has a minimum thickness of 30 m, and the fact that the gabbro outcrops farthest away from the contact are still coarse grained suggests that this dyke may be of considerable thickness.

A very pronounced magnetic anomaly underlies the hilly area between the dyke exposure and Black River about 1 km to the south (Fig. 7). Sedimentary rock is to be found along Salmon River south of the dyke outcrops, but there is no outcrop at all to be found on the hills above the river, in the area underlain by the magnetic anomaly. The magnitude of the anomaly suggests that a gabbro intrusion of considerable size either underlies the hill or is close to surface there. It is interesting to note that clusters of gabbro boulders occur in the woods along a trend of 030° Az, which corresponds to the strike extension of the dyke exposed on the river. It appears unlikely that the dyke, as exposed on the river, is the sole source of the sizable magnetic anomaly. It is more likely the dyke is merely the northwestern edge of a much larger intrusion that extends to the southeast and underlies the hill between Salmon River and Black River. Alternatively, the dyke is merely an offshot intrusion from a much larger body that underlies the entire hill.

John McDonald Brook Gabbro

Fletcher (1892, p. 35P and 149P) makes clear mention of the presence of "reddish and greenish massive felsite, trap, syenite and diorite, granular and compact, of serpentinous diorite-breccia" along John McDonald's (Ogg) Brook and surrounding fields near Sunnybrae (Fig. 5). Several traverses in

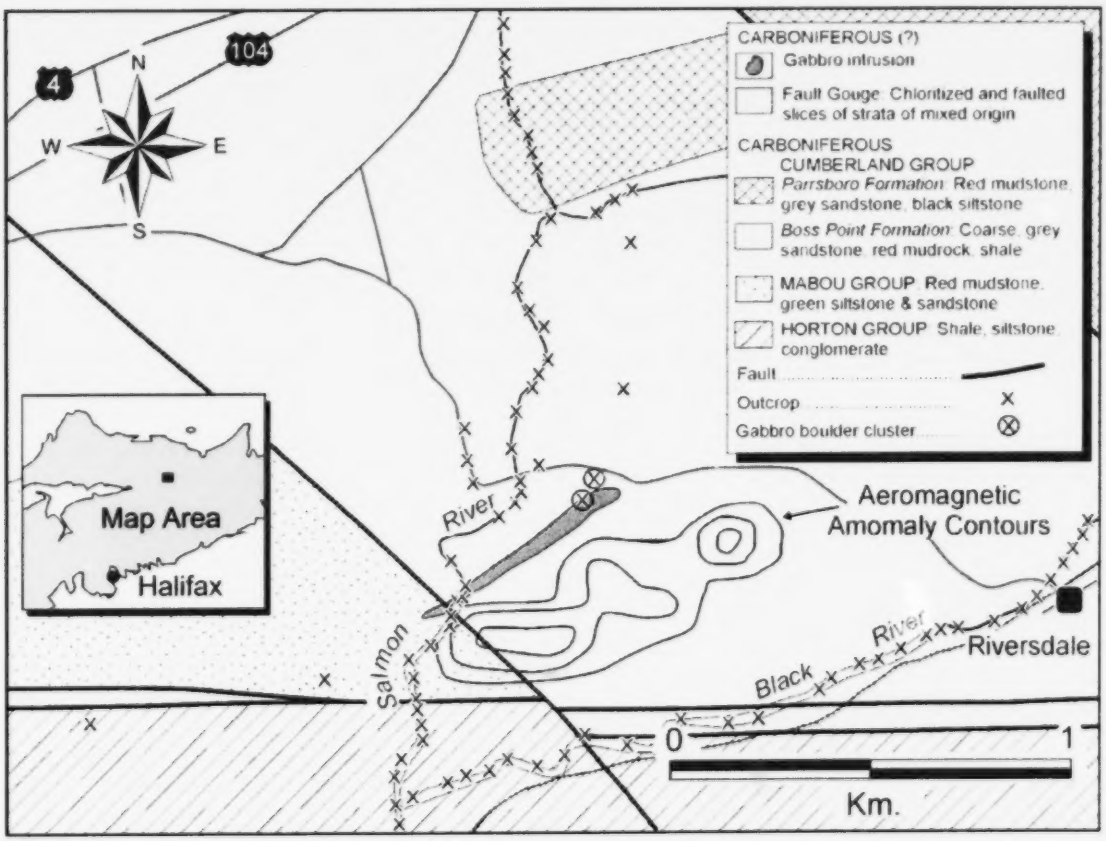

Figure 7. Geology map of the junction of the Salmon and Black rivers in eastern Colchester County, showing the location of the Salmon River gabbro.

this area failed to turn up outcrops of these rocks and, in some instances, it was found the felsite and syenite he reported were actually probably highly silicified and deformed (mylonitized) Horton Group slate. However, it is clear from outcrops that the major east-west Chedabucto Fault passes through the brook a couple of hundred metres south of the bridge on the Sunnybrae Road and forms the contact of the red-maroon siltstone and sandstone of the Mabou Group to the north with older grey slate of the Horton Group, which constitute the St. Mary's Graben to the south. Outcrops in the brook south of this structure are very considerably faulted and deformed and contain an abundance of ankerite specularite veins and associated hydrothermal alteration.

A pronounced magnetic high, elongate east-west for 1.5 km, underlies the trace of the Chedabucto Fault Zone a short distance west of John McDonald's Brook (Fig. 5). This area is found along the north-facing scarp of the St. Mary's Graben and, although no outcrops of gabbro are known, contains common boulders of coarse-grained gabbro highly veined with calcite and quartz and very much resembling the gabbro found at the Culloden Road intrusion. Boulder clusters of highly veined gabbro are common along the north face of the St. Mary's Graben in this region (Fletcher, 1892), and likely reflect the presence of many small intrusions or dykes emplaced along the major fault structures that mark this boundary. In all likelihood, the strong magnetic anomaly west of John McDonald's Brook represents an intrusion of this composition. Unfortunately, the contact relations of the pluton with its enclosing country rocks are not known, although Fletcher (1892) reports dykes and minor intrusions of such rocks in the Horton Group sediments.

Mount Thom Gabbros

Two complexes consisting of mixed mafic rock, metasediment and granite gneiss occur along the trace of the major, east-west Weatherby Brook Fault south of Steele Run near Mt. Thom (Fig. 9). The complexes correspond to an elongate magnetic high and diamond-drilling associated with exploration of the Mt. Thom Cu-Co-Au prospect, immediately to the north on the north side of Steele Run, has shown the anomalies are underlain by a mixed complex of gabbroic intrusive rock, slate, possible metavolcanics, minor granite gneiss and pegmatite (Mersereau, 1971). An examination of the diamond-drillholes (e.g. DDH-10; Mersereau, 1971) shows the rocks are indeed a mixture of rock types and their relationships are very much complicated by the high degree of faulting that has affected them. In addition, considerable hydrothermal alteration and injection of ankerite

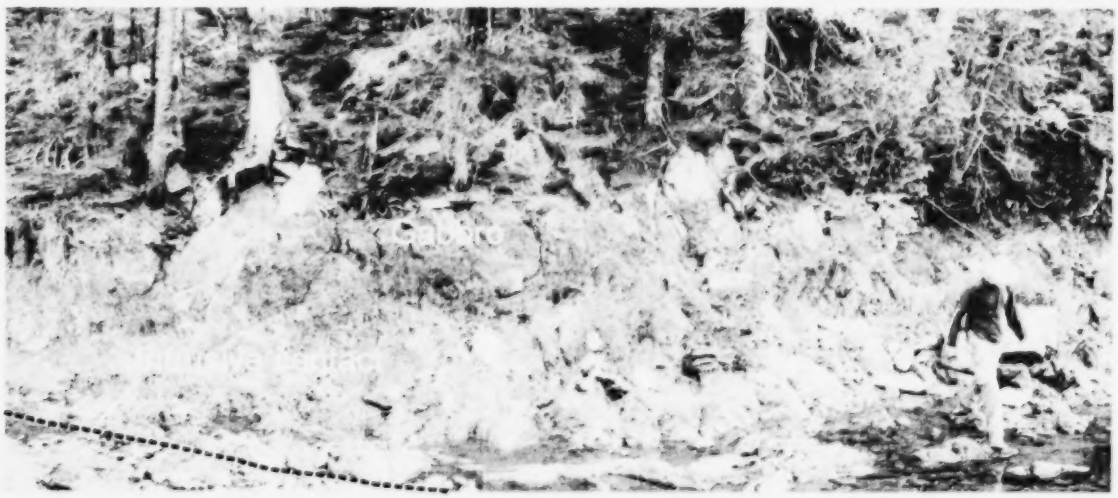

Figure 8. Intrusive contact of the Salmon River gabbro with Boss Point Formation sediments exposed on Salmon River.

and calcite veins has overprinted the rocks and further complicates recognition of their relationships. It is clear, however, that examples of the reported rock types do exist except for perhaps the metavolcanic rocks, which may just be deformed intervals of fine-grained gabbro.

The fact that these rocks occur within or adjacent to a major fault structure, suggests that they may just be fault slices of lower Paleozoic basement rock brought into their current position tectonically. As such, they may be older than the surrounding Carboniferous Mabou and Cumberland group sediments.

Felsic Plutons

Mt. Thom Granite

Exploration of the Mt. Thom Cu prospect by Esso Minerals in the early 1970s recognized the presence of granite, granite breccia and granite porphyry in diamond-drill core and outcrop (Mersereau, 1971). The granite is found within a very highly faulted zone exposed along an unnamed brook that flows north into Steele Run (Fig. 9). The main Mt. Thom mineralized showing is found immediately to the north, on the north side of Steele Run. A diamond-drill hole (Mersereau, 1971; DDH #43) was collared to drill north under some outcrops of the pinkish granite exposed on the brook, where the brook meets the powerline that passes through the Mt. Thom region (Fig. 9).

An examination of the drill core from DDH #43, and mapping along the brook between the powerline and Steele Run, shows that granite is present and that the section is clearly within a major fault zone and, in fact, may be at the at the junction of two major faults. The east-west Weatherby Brook Fault is known to pass through this area and serves to separate Mabou Group

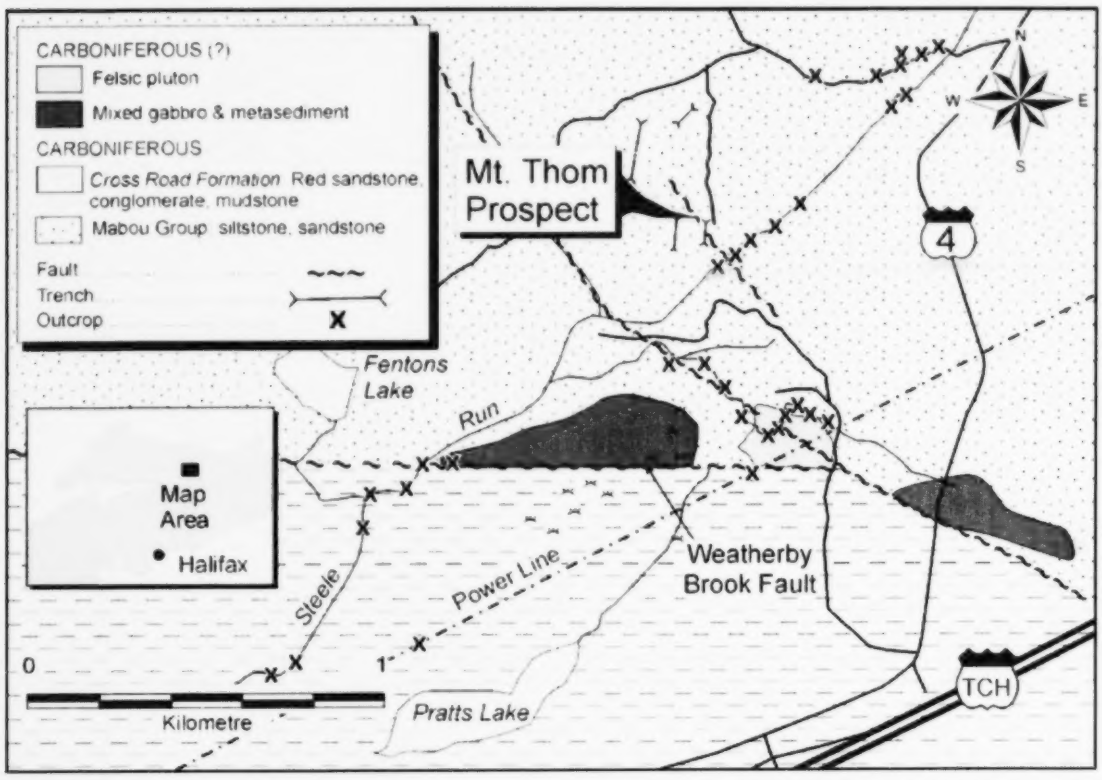

Figure 9. Geology of the Mount Thom Cu-Co-Au prospect and surrounding area showing the location of felsic and mafic intrusions along the Weatherby Brook Fault.

siltstone and sandstone to the north from the conglomerate and maroon sandstone of the Cumberland Group to the south. In addition, exploration geologists with Esso concluded that a northwest-trending fault crossed the Mt. Thom property and its trace would pass through the area of the unnamed brook. Regional mapping carried out as part of the TGI-2 project provides support for the existence of such a northwest-trending fault (Naylor *et al.*, 2005).

Although the contact relations of the granitic rocks in this area are very complicated and, in many cases, obliterated by faults, there is still evidence that the felsic rocks actually intrude Carboniferous Mabou Group sediments. Within the top 55 m (181 ft.) of DDH #43 there are several intersections of mixed granite-pegmatite dykes, some of which have sharp intrusive contacts with highly faulted and hydrothermally altered sediments. A granite porphyry breccia extends from 13 m to a depth of 45 m, and contains so many fragments of sediment that Esso geologists logged it as granitized sediment. Pegmatitic granite is found at 46, 53 and 55 m depths. From 72-73 m a fine-grained pink aplitic phase is in intrusive contact with a fine-grained greenish siltstone, probably of the Mabou Group (Fig. 10).

Outcrops of pinkish granite, porphyritic granite and brecciated granite are found locally along the unnamed brook north of where it crosses the powerline (Fig. 9). As is the case with the diamond-drill core of DDH #43, subsequent faulting has obliterated much of the original contact relations. In several places, however, one can see a fining of grain size in the granite toward contacts with the country rock sediment, suggesting chilling during intrusion. Furthermore, the compositional variability of the granite is worthy of consideration. Examples of fine-grained aplite, fine- to medium-grained granite and granite porphyry, and pegmatite are all present. This suggests that greatly varying conditions prevailed during emplacement of the felsic melts, and/or there were multiple injections. If the granite was simply the result of tectonic emplacement of fragments of previously crystallized Cobequid Highlands plutons, one would not expect such textural variation, unless there was the fortuitous situation where the pluton

Figure 10. Photograph of a sample of diamond-drill core from DDH #43 of Esso Resources Canada from the Mount Thom prospect showing the contact of fine-grained, pink, aplitic granite with Mabou Group siltstone.

siltstone and sandstone to the north from the conglomerate and maroon sandstone of the Cumberland Group to the south. In addition, exploration geologists with Esso concluded that a northwest-trending fault crossed the Mt. Thom property and its trace would pass through the area of the unnamed brook. Regional mapping carried out as part of the TGI-2 project provides support for the existence of such a northwest-trending fault (Naylor *et al.*, 2005).

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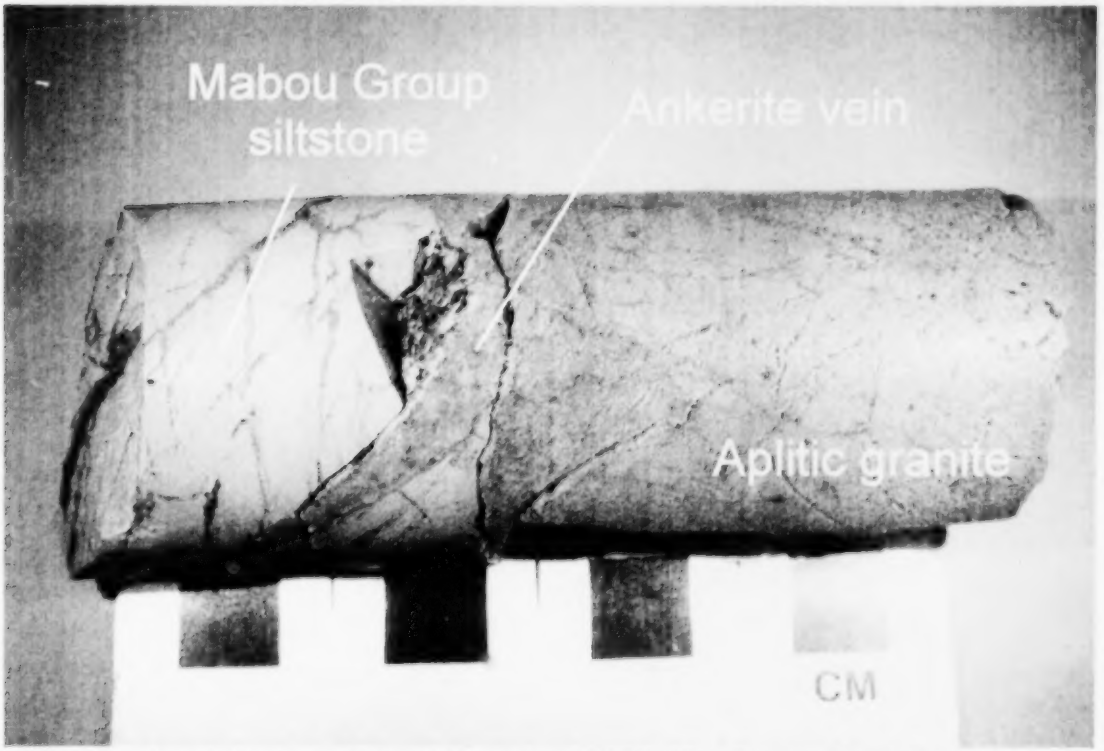


Figure 10. Photograph of a sample of diamond-drill core from DDH #43 of Esso Resources Canada from the Mount Thom prospect showing the contact of fine-grained, pink, aplitic granite with Mabou Group siltstone.

from which the fault wedges originated was itself texturally variable and inhomogeneous in composition. That situation is possible, but unlikely. It is more likely that a late-stage, felsic melt was emplaced into an active fault zone and the resultant variability of texture and composition is indicative of the changing physical and chemical conditions typical of such a situation.

Lorne Gneissic Granite

A currently producing aggregate quarry has exposed a small pluton of gneiss of hybrid composition that has a pronounced planar fabric trending 082° and dipping 78° north (Fig. 2). Fletcher (1892, p. 149P) made note of "many large blocks of green-grey, white veined gneissic diorite, the veins being compact or granular felsite." Benson (1967b) showed a single outcrop of granite in his geology map of the area.

The current quarrying operation has exposed the entire pluton. Most of the pluton has an overall monzonitic composition but portions of a more mafic dioritic composition are found, as well as pinkish rapikivi-textured granite and alaskite zones. Generally, the zones of rapikivi granite occur as monzonite in which layers of pink, K-feldspar-rich granite occur parallel to the well developed gneissic fabric. This gives the rock an overall pinkish granite look.

The contact of the pluton with the enclosing Mabou Group sediments is well exposed and the contacts are roughly parallel to the planar fabric within the pluton. This suggests that the fabric within the pluton may have developed in response to emplacement of the body into its current position. Furthermore, the degree and intensity of the planar fabric clearly increases toward the contact with the sediments. It is important to note, however, the presence of ductile deformational textures within the pluton, things like mylonitic zones, rolling of K-feldspar and quartz phenocrysts. By contrast, the contacts for the most part are fault breccias with slickensided fracture surfaces which are indicative of more high level, brittle deformation.

Evidence of hydrothermal alteration and associated specularite and sulphide mineralization abound throughout the quarry and especially toward the more deformed contact zones. In addition, the brecciated Mabou Group contact rocks are also hydrothermally altered and, in places, actually healed due to influx of carbonate and quartz into the breccia matrix. Much of the specularite mineralization is secondary and occurs filling fractures and as disseminations throughout breccia, but there are also examples of large blades of the mineral occurring within and adjacent to layers of rapikivi granite, suggesting a metasomatic origin related to the formation of the granitic layers.

Since all the observed contacts of the pluton are faults, no conclusion can be made as to whether the gneiss actually intrudes the Mabou Group or was simply brought into position by subsequent faulting. It must be said that the forces necessary to raise the pluton to a gneissic character are far more than would seem to be available at its current level of exposure. This would suggest the gneiss formed at greater depth and was brought into its current position by faults. This is not to say the pluton is not Carboniferous in age, just that it was not likely intruded to this level. A sample of the pluton is currently being age dated and this may further shed light on this aspect of its development.

Lorne Station Granite and Gabbro Complex

About 1 km northwest of the Lorne Gneiss is another operating aggregate quarry, just west of Lorne Station (Fig. 2). Benson (1967b) indicates a few outcrops of granite adjacent to the road. In the woods west of these outcrops and at the top of a prominent topographic high the current quarry operation has exposed a fairly substantial face within a mixed pink granite and gabbro complex. The rock consists of pink, medium-grained granite intruding greenish, fine-grained and somewhat altered gabbro. The rocks here very much resemble those found in the quarrying operations in the Cobequid Mountains in the area of Mt. Thom and Six Mile Brook west of Scotsburn and Saltsprings, Pictou County. Unfortunately, the quarry has yet to expose any of the Carboniferous country rock known to surround this topographic high, so no conclusions can be made as to the geological relations. However, the similarity of these rocks, compositionally and texturally, to those in the quarry operations in the Cobequids to the north, suggest the rocks here represent a basement block brought into its current position by faulting.

Trafalgar Granite

Fletcher and Faribault (1901) indicate a small intrusion of syenite outcropping on the West River St. Mary's just downstream from Trafalgar, Pictou County. Benson (1967b) also indicates the intrusion on his geology map as do Giles *et al.* (unpublished map) on their map of the Liscomb Complex. The section was examined in 2004 (Fig. 11) and the rock was found to be a muscovite-bearing monzogranite and, although deformed and with a weak planar fabric, resembles granitic phases typically found within the Meguma Zone. There is apparently no evidence to support calling the rock a syenite, as was done by Fletcher and Faribault (1901). Evidence suggests the entire block of granite is fault-bounded and is almost, if not entirely, surrounded by Horton Group clastic sedimentary rocks. The Horton Group shows no evidence of the thermal effects of intrusion. It appears the granite is merely a faulted-in remnant from one of the monzogranite plutons in the Liscomb Complex, which underlies a large area to the south.

Summary

The Carboniferous rocks of central Nova Scotia are host to several plutons of mafic and felsic

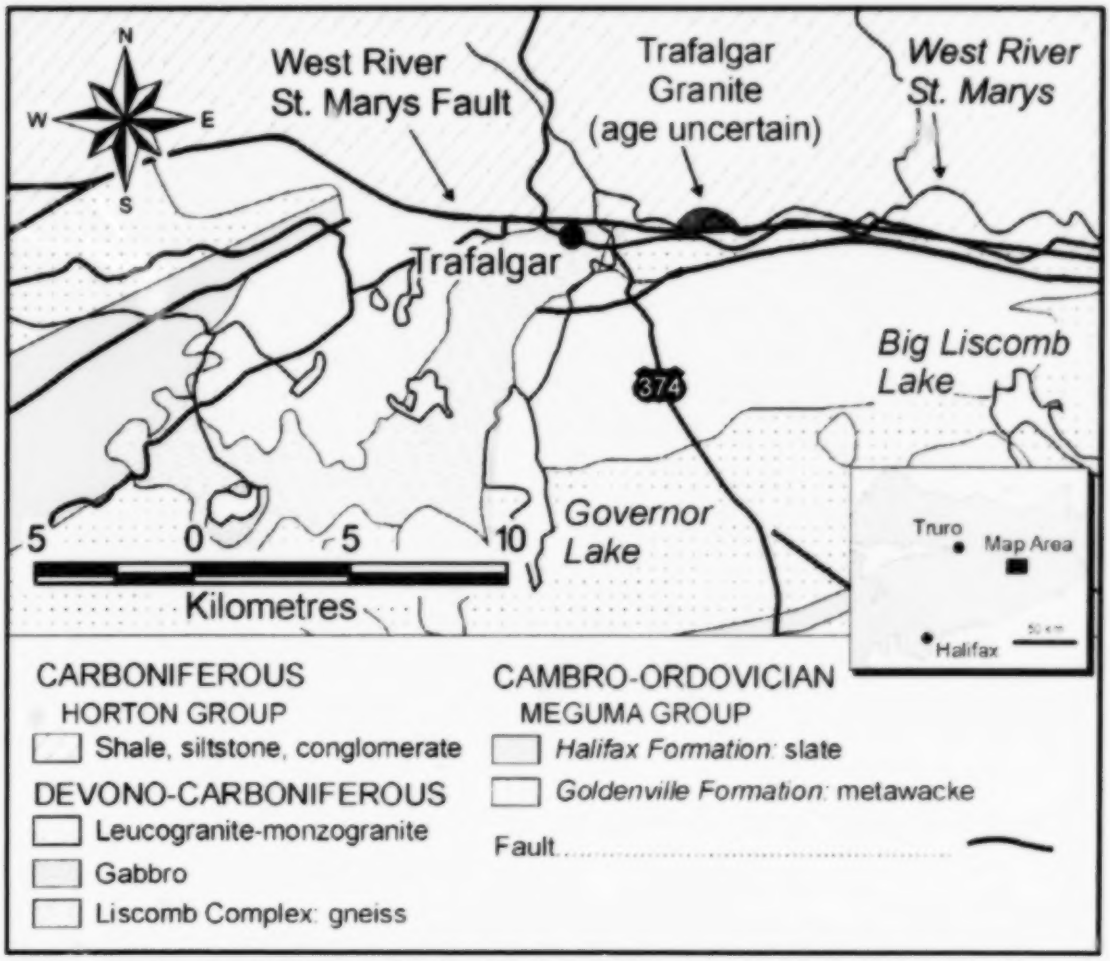


Figure 11. Geology of the Trafalgar area of northwest Guysborough County showing the location of a fault-bounded outlier of granite along the West River St. Marys Fault.

composition. There is an obvious spatial association between the plutons and fault splays related to the regional Cobequid-Chedabucto Fault Zone. This suggests that faults have played a role in emplacement of the plutons, albeit by serving as host to melts rising along the faults, or by tectonically dislodging portions of older intrusive rock and bringing them into their current position by the movement of the faults themselves. Unfortunately, the original contact relations of the plutons with their enclosing country rocks are complicated or, in some cases, completely obliterated by subsequent movements along the fault zones.

Fletcher (1902 a and b), in geology maps of southern Pictou County and eastern Colchester County, indicates numerous small mafic and felsic intrusions in the Carboniferous rocks. Fletcher (1892) makes frequent mention that at least some of these intrusions intrude their enclosing host rocks, as opposed to simply being faulted into place along faults related to the CCFZ. At some of the sites (Limerock and John McDonald Brook) it was found that highly bleached and altered sandstone units were mistakenly identified as felsite. However, there are many sites at which mafic and felsic intrusive rocks are definitely present. Field examinations in 2004 have shown that some of these plutons are emplaced along fault structures and have had their contact relations obliterated, or so complicated by post-emplacement fault movements, that their origin still remains a mystery (e.g. Lorne Gneissic Granite, Lorne Station Granite and Gabbro Complex). At some sites though, intrusive relations are present that indicate the plutons actually intrude their enclosing sediments (e.g. Moiche Hill Gabbro and Carbonate Breccia, Centredale Gabbro, Marshdale Gabbro, Salmon River Gabbro and East Mountain Gabbro, Mt. Thom Granite).

The observed field relations indicate mafic intrusions definitely intrude Carboniferous sediments of the Windsor Group (East Mountain Gabbro), Mabou Group (Moiche Hill, Marshdale, Centredale gabbros and Mt. Thom granite) and Boss Point Formation (Salmon River Gabbro). The youngest Carboniferous rocks observed to be intruded belong to the Boss Point Formation.

References

Bell, W. A. 1929: Horton-Windsor district, Nova Scotia; Geological Survey of Canada, Memoir 155.

Belt, W. A. 1964: Revision of Nova Scotia Middle Carboniferous units; American Journal of Science, v. 262, p. 653-673.

Belt, W. A. 1965: Stratigraphy and paleogeography of the Mabou Group and related Middle Carboniferous facies, Nova Scotia, Canada; Geological Society of America Bulletin, v. 76, p. 777-802.

Benson, D. G. 1967a: Geology of the Hopewell map-area, Nova Scotia; Geological Survey of Canada, Memoir 343, 58 p.

Benson, D. G. 1967b: Geology, Hopewell, Nova Scotia; Geological Survey of Canada, Map 1215A, scale 1:63 360.

Benson, D. G. 1974a: Geology of the Antigonish Highlands, Nova Scotia; Geological Survey of Canada, Memoir 376, 92 p.

Benson, D. G. 1974b: Geology, Lochaber, Nova Scotia; Geological Survey of Canada, Map 1360A, scale 1:50 000.

Black, D. L. 1995: Report of work performed, East River of Pictou claim group, Pictou Co., N. S.: Nova Scotia Department of Natural Resources, Assessment Report AR-95-098.

Calder, J. H. 1998: The Carboniferous evolution of Nova Scotia; *in* Lyell: The Past is the Key to the Present, eds D. J. Blundell and A. C. Scott; Geological Society, London, Special Publications, v. 143, p. 261-302.

Donohoe, H. V. Jr. and Wallace, P. 1982: Geological map of the Cobequid Highlands, Colchester, Cumberland and Pictou counties, Nova Scotia; Nova Scotia Department of Mines and Energy, Map 82-8, scale 1:50 000.

Fletcher, H. 1892: Geological surveys and explorations in the Counties of Pictou and Colchester, Nova Scotia; *in* Geological Survey of Canada, Annual Report 1890-91, vol. V, part II, Report P, 183 p.

Fletcher, H 1902a: Geological map of Westville: Geological Survey of Canada, Old Series Geology Map 610 (Sheet #47), scale 1:63 360.

Fletcher, H. 1902b: Geological map of Stellarton; Geological Survey of Canada, Old Series Geology Map 598 (Sheet #43), scale 1:63 360.

Fletcher, H. 1902c: Geological map of Truro; Geological Survey of Canada, Old Series Geology Map 636 (Sheet #57), scale 1:63 360.

Fletcher, H. 1902d: Geological map of Earltown; Geological Survey of Canada, Old Series Geology Map 637 (Sheet #58), scale 1:63 360.

Fletcher, H. and Faribault, E. R. 1901: Geological map of Trafalgar; Geological Survey of Canada, Old Series Geology Map 593 (Sheet #42), scale 1:63 360.

Giles, P. S. 1982: Geology map of the Eureka area, central Nova Scotia; Nova Scotia Department of Mines and Energy, Map ME-82-3, scale 1:50 000.

Giles, P. S., Beohner, R. C. and Ryan, R. J. 1979: Carbonate banks of the Gays River Formation in central Nova Scotia; Nova Scotia Department of Mines and Energy, Paper 79-7, 57 p.

Giles, P. S., Chatterjee, A. K. and Ford, K. L. unpublished map: Geology of the Liscomb Complex, (11E/01, 11E/02, 11E/07 and 11E/08), southern Nova Scotia; Geological Survey of Canada, scale 1:50 000.

Mersereau, T. G. 1971: Geological report - Truro-New Glasgow project, Mount Thom - area "A"; Nova Scotia Department of Natural Resources, Assessment Report 11E/06D 07-D-44(09).

Mersereau, T. G. 1974: Report on work, Mount Thom, Nova Scotia; Nova Scotia Department of Natural Resources, Assessment Report 11E/11A 13-M-18(01).

Murphy, J. B., Keppie, J. D. and Hynes, A. J. 1991: Geology, Antigonish Highlands, Nova Scotia; Geological Survey of Canada, Map 1749A, scale 1:50 000.

Naylor, R. D., Brisco, D. C., Fisher, B. E., Giles, P. S., Goodwin, T. A. and Kontak, D. J. 2005: A summary report on the work undertaken for the Nova Scotia component of the Targeted Geoscience Initiative (phase 2); *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 69-72.

PePiper, G. and Piper, D. J. W. 2001: A synopsis of the geology of the Cobequid Highlands, Nova Scotia; Atlantic Geology, v. 38, p. 145-160.

PePiper, G., Reynolds, P. H., Nearing, J. and Piper, D. J. W. 2004: Early Carboniferous deformation and mineralization in the Cobequid shear zone, Nova Scotia: an $^{40}Ar/^{39}Ar$ geochronology study; Canadian Journal of Earth Sciences, v. 41, p. 1425-1436.

Rankin, L. D. 1997: Report of work, East River of Pictou claim group; Nova Scotia Department of Natural Resources, Assessment Report AR-97-038.

Ryan, R. J., Boehner, R. C. and Calder, J. H. 1991: Lithostratigraphic revision of the Upper Carboniferous to Lower Permian strata in the Cumberland Basin, Nova Scotia, and regional implications for the Maritimes Basin in Atlantic Canada; Bulletin of Canadian Petroleum Geology, v. 39, no. 4, p. 289-314.

Wright, J. D. 1975: Iron deposits of Nova Scotia; Nova Scotia Department of Mines, Economic Geology Series 75-1, 154 p.

Aggregate Program Activities in 2004

G. A. Prime

Introduction

The primary focus of the Aggregate Program is evaluation of the mineral aggregate resource in Nova Scotia. This includes (1) bedrock that can be used for the production of crushed stone and (2) surficial deposits consisting of glacial sand and gravel. Using methods such as field mapping, air photo interpretation, laboratory testing and thin section petrography, data are continually being collected and processed to gain a better understanding of the resource. The long-term goal is the preparation of a publicly accessible database which can be used to identify aggregate potential for resource development purposes throughout the province.

Research conducted under this program also has an important educational value. This reflects the fundamental role that aggregate plays in modern societies and the accelerating pressure that the resource faces from over-use and development access problems. In effect, this information permits a glimpse into the future of the resource. This program provides an opportunity to inform stakeholders (i.e. government, industry and tax payers) of resource concerns and potential solutions that could be implemented to mitigate current trends. Protecting this valuable resource and ensuring its responsible use should be a priority for everyone in society.

In addition to the ongoing geoscientific research, the Aggregate Program provides assistance to a broad range of clients including the aggregate industry, consulting firms, government agencies and private citizens. Client needs can vary from requests for geotechnical data, to environmental issues, to aggregate product information. A final important component of the program is the constant evaluation of the industry and markets to determine if new development potential may exist for Nova Scotia's aggregate resource.

The focus of the Aggregate Program during 2004 was the Annapolis Valley Project and the Western Halifax Regional Municipality (HRM) Project (Fig. 1). A description of activities conducted during the year, and a discussion of the current status of these projects is provided below.

Annapolis Valley Project

A major, continuing project conducted in recent years is a regional assessment of the aggregate resource in the Annapolis Valley and adjacent areas. The focus of the research is a field study covering Hants, Kings, Annapolis, Digby and Yarmouth counties (Fig. 1). Through air photo interpretation, field investigation and a sampling program, the area is being evaluated for its bedrock (crushed stone) and surficial (sand and gravel) aggregate potential. The field component of the study also provided an opportunity to examine the region for other industrial minerals with development potential, including clay deposits and specialty stone products. The specialty materials included aggregate for landscaping, armourstone, dimension stone and other manufactured rock products.

Project Status

The 2004 field season saw the completion of the fieldwork component of the project. This included work on Digby Neck, the Fourth Lake area, Cambridge, Leminster and Benjamins Mill. During the same period, Paul Barker and the Geoscience Information Services Section completed the digital base maps which will be used to construct the 1:50 000 aggregate resource maps. This important aspect of the project consisted of compiling pre-existing bedrock and surficial geological maps for the five counties. Finally, the large backlog of bedrock and gravel samples in storage were analyzed for aggregate properties by Jacques Whitford Limited.

Overview of Project Results

Although a large amount of data entry and analysis

Prime, G. A. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 93-99.

remains to be completed in 2005, the aggregate potential for the region can be discussed in general terms. This discussion will primarily focus on the geotechnical aspects that affect rock quality or the suitability of a deposit for resource extraction. Other land-use or environmental issues that could affect resource development were documented, but are beyond the scope of this discussion. They will be presented in the digital database and final report.

Bedrock Potential

The primary bedrock aggregate potential in the region can be found in the granitic rocks (the South Mountain Batholith, the Brenton Pluton and the Wedgeport Pluton), the North Mountain basalt, quartzite (metagreywacke) of the Goldenville Formation, some of the Silurian volcanic rocks and quartzite of the White Rock Formation. This assessment generally reflects the hardness and durability of many of the rocks found in these bedrock units.

The best aggregate potential in the granitic rocks of the South Mountain Batholith (SMB) is generally found in fine- to medium-grained stone. This is attributed to the low frequency or absence of microfractures which normally cause stone weakness and make the rock prone to water entry and weathering. There is also an absence of large feldspar crystals which are common in the coarse-grained rock. Although these large crystals or grains are hard, they tend to be brittle and create a mechanical weakness in rocks where they are present.

Another factor favouring fine-grained rock of the SMB is a general absence of near-surface weathering. When highly fractured, altered granitic bedrock is exposed to surface conditions such as water infiltration and freeze-thaw cycles, the bedrock fragments *in situ* over time. This weathering of the bedrock surface creates friable, disaggregated rock which can be several metres in thickness. (This granitic bedrock is fragmented to the point that it can be ripped with an excavator.) The problem is quite common in the coarse-grained granitic rocks, which the author speculates is caused by a combination of abundant micro-fractures and pervasively altered bedrock. These weathered zones are not only unacceptable for construction aggregate but would have to be treated as overburden, resulting in costly removal of the materials to get at the 'solid' rock beneath. The characteristics of the bedrock that lead to weathering, however, probably are present in the rock below the weathered zone, suggesting that this bedrock would probably be unacceptable for construction aggregate as well. These weathered zones are quite common in the SMB rocks.

The Brenton Pluton near Yarmouth, which is distinct from the SMB, also appears to make high quality construction aggregate. This unit is the primary source of stone in the Yarmouth area. The rock is deformed, with a faint schistose fabric. It appears to be quite 'fresh' and unaltered, with little evidence of surface weathering. Aggregate test results for the rock samples collected in this study have not been assessed at the time of this writing. An assessment of the Brenton Pluton will be provided in the final report for the project.

The Wedgeport Pluton consists of comparatively hard, unaltered rock, suggesting that it may be suitable for construction aggregate. One potential drawback is the relatively coarse-grained nature of the stone. An assessment of this intrusive for aggregate potential cannot be completed until test results for the rock samples have been evaluated.

The Jurassic basalt of the North Mountain can make excellent aggregate, but this depends on the composition of the rock. This 400 m thick package of tholeiitic volcanic rocks has been subdivided by Kontak and Dostal (2002) into upper-, middle- and lower-flow units. The lower and upper units are each massive, single flow units characterized by columnar-jointed rock. They are separated by the middle unit which consists of a complex sequence of amygdaloidal flows. The amygdular zones occur in the upper part of these lava flows, the result of gas bubbles rising toward the surface following deposition of these molten materials. Subsequently the vesicles were infilled with zeolites.

The rocks in the upper- and lower-flow units have been used extensively for construction aggregate. This reflects the solid nature of these massive homogeneous rocks. The middle-flow unit, on the other hand, is less likely to produce good aggregate. This reflects the friable nature of the amygdaloidal units. Similar to the granitic rocks, near-surface weathered zones in the basalts (possibly present in all three flow units) should be

Figure 1. Location map showing general project areas of the Aggregate Program in 2004.

avoided due to weakness in the stone. The areas containing friable rock (including the zeolitic and weathered zones), which is substandard for the production of construction aggregate, are easily identified in the field as shallow 'pits' where the bedrock has been ripped with a bulldozer or excavator. The middle-flow unit commonly is expressed as topographic lows due to preferential weathering associated with glaciation. It generally occurs as the central area on top of the North Mountain and runs parallel to this highland's northeast-southwest trend along its entire length. Although current geological maps do not show these important unit subdivisions, it is anticipated that they can be delineated through air photo interpretation and will be identified on the final aggregate resource maps.

The quartzite of the Goldenville Formation of the Meguma Group has historically been the aggregate of choice in the western half of mainland Nova Scotia. This largely reflects the durability of this rock and its widespread presence in the region. Within this formation, however, there is the common presence of less desirable rocks such as slate (metamorphosed shale) and argillite (metamorphosed siltstone). The layering associated with these fine-grained rocks commonly makes them soft, friable and prone to water entry as aggregate particles. The best quality quartzites for construction aggregate are those deposits that contain a minimum of fine-grained, foliated rock. They are generally recognizable as stacked sequences of thick beds of quartzite with minimal interbeds of fine-grained rock. As a general rule the

individual beds of quartzite within the package should be metres in thickness. The author speculates that, due to depositional conditions at the time, areas of thinner beds (≤ 1 m) are more likely to contain higher amounts of slate or siltstone interbeds separating the quartzite units. This opinion remains to be verified by geoscientists who are more knowledgeable about the sedimentological characteristics of the Meguma Group rocks.

Areas where the Goldenville Formation quartzites are near contacts with the Halifax Formation slates (informally referred to as the 'transition zone') should be avoided or approached with caution when looking for a quarry site. These areas, which are defined by interlayering of coarse-grained (quartzite) and fine-grained rock (slate and argillite), usually contain an abundance of deleterious slate and siltstone. There is also a higher probability of encountering acid-generating minerals (sulphides) and metals, which can be damaging to human health and the environment (e.g. arsenic and lead).

Metamorphosed quartzites of the Silurian White Rock Formation have been used for construction aggregate. Although not a lot of work was done on this rock group as part of this study, the potential of stone appears to largely depend on the depositional conditions of the rock. Similar to the Goldenville Formation, the best areas for quarrying host thick, massive quartzites with minimal fine-grained sedimentary rocks. Samples have been collected and are currently being tested for aggregate quality.

Silurian and Devonian volcanic rocks also appear to have good potential for construction grade aggregate. This generally reflects the hardness and durability of the rock. Although little work has been done on these rocks as part of this study, the best areas for exploration would be volcanic packages where there are minimal interbedded softer sedimentary rocks such as slate or siltstone. Samples have been collected and are currently being processed for aggregate tests.

Surficial Potential

Surficial deposits that can be used for aggregate primarily consist of glacial sand and gravel. These materials are found throughout the region as ice-contact, proglacial and glaciomarine sediments deposited during the final stages of Pleistocene glaciation. Ice-contact stratified drift deposits formed in meltwater channels on, in, or under the ice during stages of ice melting and glacial retreat. They are usually mound-shaped and include eskers, kames and kame deltas. Proglacial deposits formed at the front of the melting ice in shallow, high energy streams. These outwash plain deposits are characterized by a planar surface and are usually aerially extensive. The glaciomarine deposits were produced during the late stages of ice melting or following deglaciation as coarse-grained Gilbert-type deltas or raised beaches. The deltaic deposits formed where outwash streams abruptly dumped their sediment load in standing water along the marine shoreline. Raised beaches formed when sea levels were higher relative to the land at the time due to depressed land associated with the former ice loading. When the land eventually rebounded, the sand and gravel beaches were raised above the modern shoreline. This effect only occurs in those shoreline areas where the land has rebounded faster than sea level has risen.

The value of glacial deposits as sources of sand and gravel is a reflection of their quality, size and location. Most of the gravel in the region would be classified by the author as moderate in terms of quality. This reflects the lithological composition of the clasts that have been produced by erosion of the source rock. Although the stone that is incorporated into glacial ice during its advance covers the spectrum of rock types found in the underlying bedrock in the area, the process is not random. This is because glacial erosion tends to preferentially wear and break down bedrock surfaces that are mechanically weakened due to their lithological composition, structural deformation or the presence of alteration minerals. Rocks in the region that fit into these categories include slate, unmetamorphosed shale and sandstone, weathered granite, weathered basalt, zeolitic basalt and rock in shear zones. Although most gravel contains a significant amount of durable rock, the presence of unsound or deleterious rock in comparatively small proportions can negatively impact the overall quality of the materials. Much of the gravel overlying the Triassic redbeds on the Annapolis Valley floor, the basalts of the North Mountain and the granites of

the South Mountain, would not pass specifications for most high quality construction aggregate products. However, these materials are (and will continue to be) used for local markets in applications where aggregate quality is less significant (e.g. surfacing driveways, back fill, gravel road maintenance).

A small proportion of gravel deposits contain pyritic slate clasts in unacceptable amounts. These sulphides can have a negative impact on the environment because of the potential of increasing acidity in streams. Gravel containing pyritic slate usually occurs near (or overlying) slate bedrock.

Although new sand and gravel deposits were identified as part of this study, the vast majority of the deposits in the region are well known to the aggregate industry. This reflects decades of use by the industry and the ongoing discovery of deposits by land owners during land tillage or excavations for other purposes. The last twenty to thirty years have seen the construction of hundreds of new access roads throughout the region for purposes such as forestry management and cottage developments. As a result, the hundreds of kilometres of roads that criss-cross the region have intersected a large number of sand and gravel deposits. The heavy equipment operators who make the roads are extremely adept at identifying these glacial sediments. Modern forest harvesting practices, such as clear cutting, have also visually exposed many of the mound deposits to those who understand the significance of these land forms. Undoubtedly, other deposits will be discovered in the future; however, many of them will remain hidden for a long time because they are covered with unsorted till. Research done in Hants County by Dr. Ralph Stea of NSDNR has identified sand and gravel deposits below substantial thicknesses of till. The author has also recorded several sand and gravel deposits overlain by till in the region.

Another important indicator or predictor of the presence of sand and gravel deposits is regional topography. Observations by the author suggest that there is a high probability of finding ice-contact mounds where there are indentations or notches in the North Mountain and South Mountain adjacent to the Annapolis Valley floor. When the glacial ice was melting, pre-existing stream and ice-carved valleys became the natural pathways for water drainage and the development of sediment-laden meltwater channels. Eskers and kame deltas commonly formed at the base of the notches. Today these areas contain large, modern streams. Examples of large sand and gravel deposits that are found at the base of the South Mountain include Windsor Forks, Nictaux Falls, West Paradise and Bridgetown. Less commonly these deposits are observed along the base of the North Mountain (e.g. near Middleton). Although most of these deposits have probably been found, field work combined with an examination of air photos should reveal new deposits in the future. This exploration tool is also applicable to the margins of other highland areas in the province.

Identification and assessment of sand deposits is another significant component of this project. Natural sand is an important commodity in a variety of applications such as concrete, asphalt, masonry sand and traction sand. The Halifax-Dartmouth area, for example, uses hundreds of thousands of tonnes of sand annually. Due to an absence of these materials near Metro, they are hauled long distances from areas in Hants and Kings Counties. The situation is placing severe pressure on this valuable, nonrenewable resource in the study area. The current research will help to better define the resource and draw attention to concerns regarding its future.

Other Industrial Mineral Occurrences

Several new industrial mineral occurrences were recorded as part of this study. Glaciolacustrine clay deposits were identified in several locations in the study area. Lower Carboniferous sandstone, Goldenville Formation quartzite with closely-spaced joints, and some of the columnar-jointed Jurassic basalt may offer potential as dimension stone for local and export markets. Blocky quartzite boulders found in thick, stony till mounds (e.g. Beaver River Till) could possibly be extracted for applications such as drywall fences and landscaping. A recent study initiated by the author and conducted by Coastal BioAgresearch Ltd. (Termeer, 1996) suggests that finely ground zeolitic basalt may act as a soil amendment or conditioner. This may have important implications for farming and the environment in the future. It is unknown if these industrial mineral occurrences and research suggestions have economic potential;

however, they are of interest and will be discussed at length in the final report as possible development opportunities.

Other Data

Although this investigation has focused on the geotechnical aspects of the stone resource in the region, a variety of other data was collected because of its relevance to resource evaluation. This included land-use issues and environmental factors. For example a high-quality aggregate deposit is just data on a map if it can't be developed because of an overlying subdivision, or is found in an area protected by legislation. Due to their porosity and permeability, some of the glacial deposits are important aquifers which should be protected for the future. The recording of abandoned pits may be significant from a subsequent land-use perspective. Depending on the characteristics of the sites, they may have a future use such as trout farming or as an apiary.

Finally, the field study also provided an opportunity to record other geoscientific data that are not connected to the assessment of the resource but may have relevance in the future. The very nature of aggregate extraction means the progressive removal of the materials in pits and quarries, which contain an abundance of geological information. Although the data collected during these site visits is, in effect, a 'snapshot in time and space', the author feels that it is important to document this information before the deposits disappear.

Anticipated Results of Study

The outcome of this research will be a collection of point data, site descriptions and aggregate resource maps in digital format. More than 4000 stations have been documented and approximately 200 samples collected for analysis. Hundreds of photographs taken throughout the region will be digitally scanned and attached to the digital data-base being constructed for this project. A summary report describing the results of the research will be the final phase of the work.

Western HRM Project

The Halifax Regional Municipality (HRM) is the largest aggregate market in Atlantic Canada, consuming more than 3 million tonnes of crushed stone from local quarries annually. The aggregate is used in a wide variety of construction applications including Portland cement concrete, roads, septic fields, back fill and erosion control. Although much of the material is used for residential and commercial purposes, a large component of the stone is used in public works projects such as highways, concrete bridges and underground services. As a result these basic materials are fundamental to the functioning of this urban community.

The region has been extremely fortunate to have local sources of high-quality aggregate. The quality of the materials is important from the perspective of product safety and maximizing the life span for structures such as concrete overpasses and highways. Premature repair or replacement of these expensive structures is extremely costly. The proximity of quarries to markets is equally important, given that transportation costs are the highest component in the delivered price of the stone. Thus the cost and quality of these bulk construction materials are major considerations for public works agencies and the taxpayer who provides the funds for the community's infrastructure.

Although the aggregate industry near Metro is currently thriving, a recent aggregate resource study by DNR (Prime, 2001) concluded that the future is less certain. Concerns centre on the urban sprawl which is taking place in the fringe areas where resource potential still exists. Encroachment by land uses considered incompatible with quarrying (e.g. residential development) is sterilizing the resource land at an accelerating rate. The construction associated with this urban and suburban expansion is also accelerating the consumption of quarry stone. While the pressure on aggregate reserves increases, attempts to open new quarries near Metro have been unsuccessful. Eventually access to the local resource will disappear, leaving the region with expensive,

distant choices for obtaining these vital materials.

In an attempt to mitigate this trend the Mineral Resources Branch of NSDNR is re-examining the aggregate potential in the region to determine if new quarry development is possible. The focus of the Western HRM Project is the identification of high-quality stone in strategic locations to the west of Metro (Fig. 1) where impacts to the environment and communities will be minimized. By comparing resource and land-use maps with the property ownership database, an area was determined to have optimal conditions for future aggregate development. This included the quality of the stone, proximity to market, and property ownership that is perceived to be favourable for resource development.

A field study was conducted and samples collected for analysis. Aggregate test results indicate that many of the fine- to medium-grained granitic rocks in the study area exhibit the characteristics of high-quality construction aggregate. In order for a quarry to be successful at this location, DNR proposes the construction of a dedicated access road from the aggregate operation to a nearby primary highway by means of an overpass connector. This would allow a quarry development site potentially as close as 7 km from a sizeable community. This distance would permit the hypothetical operation to be competitive on the western side of the Metro aggregate market. Direct access to a major highway would also reduce trucking through communities. Another major benefit is the land ownership. The land owner has extensive acreage which should permit natural buffers around a quarry and reduce the likelihood of encroachment associated with urban development.

Project Status

Although the results look promising, new resource development in this area will ultimately require the interest and co-operation of public and private stakeholders. A report is in the final stages of review and will be released as soon as possible.

Resource Inquiries are Encouraged

Anyone with questions about any aspect of the aggregate resource is encouraged to contact the author at Department of Natural Resources (902-424-8146). The DNR library also carries a comprehensive assortment of reports, journals, maps and other publications which can be useful in identifying and evaluating aggregate deposits. Finally, there is also a broad range of other geological expertise among the staff at the department which can be accessed to obtain additional information on the geology of the aggregate resource.

References

Kontak, D. J. and Dostal, J. 2002: Geological setting and petrology of the North Mountain Basalt, southern Nova Scotia; Geological Society of America, Northeastern Section - 38th Annual meeting, Session No. 37, Paper 37-5, 2 p.

Prime, G. 2001: Overview of bedrock aggregate potential in the Halifax-Dartmouth metropolitan area, Nova Scotia; Nova Scotia Department of Natural Resources, Economic Geology Series ME 2001-1, 74 p.

Termeer, W. 1996: Testing the suitability of Nova Scotia aggregate fines as rock fertilizers/soil conditioners; conducted by Coastal BioAgresearch, funded by Nova Scotia Department of Mines and Energy under the Canada-Nova Scotia Mineral Development Agreement; 57 p.

Can Glacial Till be Mined for Gold in Nova Scotia?

R. R. Stea, R. F. Mills, P. K. Smith and T. A. Goodwin

Introduction

The question posed in the title of this report was sparked by the discovery in 2003 of a previously unknown adit sunk into glacial till in Tangier, Halifax County (NTS 11D/15). The adit was found during excavation of a gravel pit 300 m southeast of the main mining district (Figs. 1, 2). The tunnel is ~60 m long and was dug into a stony till deposit (Beaver River Till) at the contact with an underlying reddish, silty till (Lawrencetown Till). Panning of the upper till in the adit revealed abundant fine gold and some millimetre size nuggets. Further exploratory panning revealed gold in the Beaver River Till across the entire face (~125 m) of the gravel pit.

The adit could have been an exploratory tunnel for a lode-gold source or a form of placer mine. The elevated gold in till adjacent to the adit and the lack of evidence for bedrock veins along strike of the adit, suggest the placer mine possibility. A wood fragment (plank) and 'artifact' were found in the tunnel by property owner Graham Cooper (Fig. 2). The 'artifact' is a 2" by 6" piece of board with holes cut in either end, perhaps an end board of a cart (P. Finck, personal communication, 2004). The plank fragment was radiocarbon dated and found to be modern, based on virtually 100% of the radiocarbon activity of the oxalic acid standard (GSC- 6844; R. McNeely, personal communication, 2005). This 'modern' age designation can accommodate ages as old as the 1920s or 30s, based on the error margins of the radiocarbon date, but unlikely much before that time. The adit may predate the wood, if the wood was introduced by a later exploration, but Graham Cooper (personal communication, 2004) has no recollection of any tunnel on his property. Unfortunately there appears to be no oral or written record of placer mining activity or exploratory adits in Tangier at that time. The Nova Scotia Annual Report of Mines (1867), however, documents placer gold workings in the vicinity of Tangier, including the discovery of a 27 oz. nugget. The location of these placer workings are uncertain and may have been in the vicinity of Copper Lake (Fig. 1).

Mining of tills in Nova Scotia is not a new idea. A newspaper report in the 1880s (NSDNR, 1887) describes the mining of glacial till at the Moose River Gold Mine (parentheses are our comments):

> "On six or seven areas the surface soil (**till**) down to the bedrock, an average of over seven feet, is gold-bearing, and will all pay to crush when Mr. Touquoy completes a ten stamp mill, which he is now preparing to put up. One hundred and forty-seven tons, quarried from different places on the surface, yielded 12 oz., 12 dwts., 10 grs., different lots yielding from $1.00 to $3.50 a ton (**1880 prices!**). Mr Touquoy estimates that it could be mined and milled for 50 cents a ton."

Bouldery deposits of glacial till cover most of the 64 lode-gold districts in the Meguma Terrane. During the last glaciation, local ice caps left a trail of eroded and transported gold-rich debris. Prospecting in the till led to the first documented bedrock gold discovery in the mid 1800s. Since that time till deposits have been used as an effective prospecting tool for lode deposits, but are generally considered to be a hindrance in mine development. It is the purpose of this paper to evaluate the economic potential of a placer gold deposit at Tangier and, by analogy, elsewhere on the Meguma Terrane. The study will have the added benefit of enhancing the understanding of glacier dispersal processes of gold in till and, therefore, will aid in the search for buried lode-gold sources.

Geology of the Tangier Gold District

It is reported that the discovery of lode gold at Tangier was the first in Nova Scotia, dating back to 1860 (Malcolm, 1929). The main development at the district took place from the Kent Shaft, which is

Stea, R. R., Mills, R. F., Smith, P. K. and Goodwin, T. A. 2005: *in* Mineral Resources Branch, Report of Activities 2004, Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 101-115.

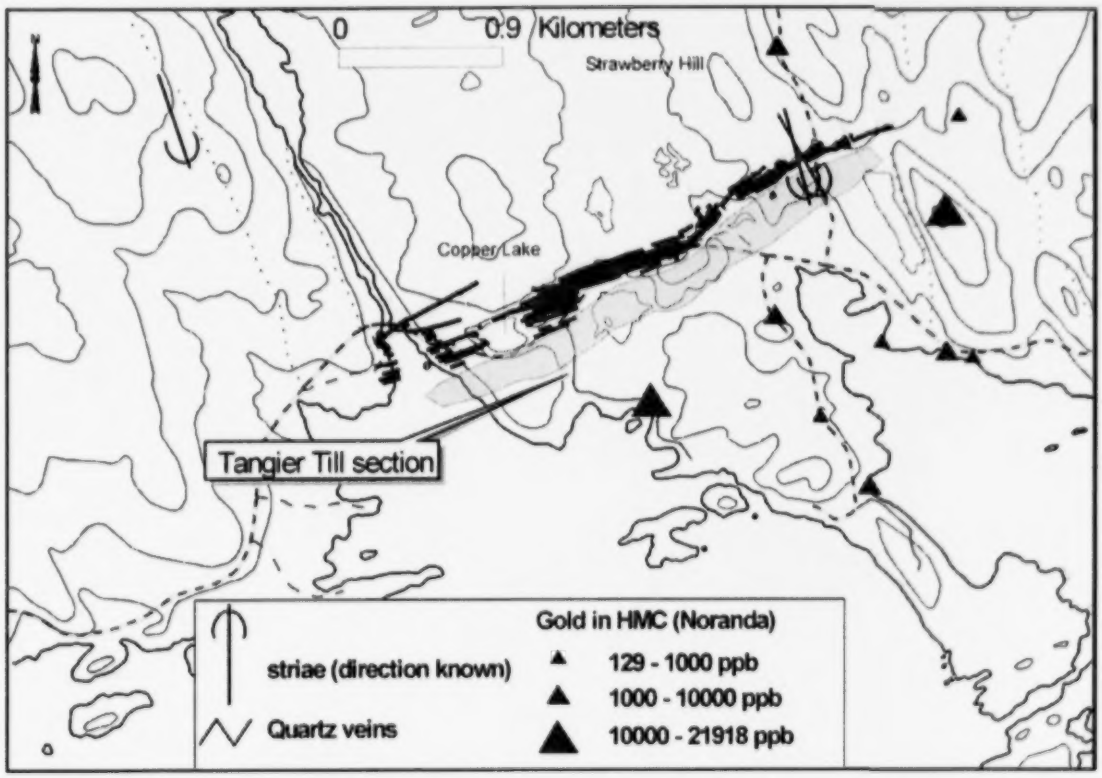


Figure 1. Map of the Tangier Gold District, showing gold veins and location of the till section analyzed in this study. The shaded region represents the potentially mineable "window" of till deposits down-ice of the Tangier Gold District. Data on gold in heavy mineral concentrates (HMC) are from a previous survey (Dimmel, 1983).

located immediately east of the present Blueberry Hill mine in the village of Tangier along the north side of Highway #7 (Fig. 1). Approximately 70 gold-bearing veins have been identified in the vicinity of the Blueberry Hill mine, producing 26,000 oz. of gold. In addition to other smaller veins that occur within the mine sequence adjacent to these veins, numerous others occur along strike toward the east in the Strawberry Hill and East Zone areas (Fig. 1).

The deposit is hosted by slate and metagreywacke of the Cambro-Ordovician Meguma Group, which is characterized by tight, upright regional folding with penetrative slaty and pressure solution cleavages. Regional biotite facies metamorphism is common throughout the district. Auriferous veins have been affected by both regional deformation and metamorphism. In addition, locally developed shear deformation is superimposed on both veins and host rocks, in part, leading to mylonitic textures in some mineralized veins (e.g. Marker Vein; Smith, 2002).

Carbonatization, sulphidization and sericitization are the main alteration types recognized at the deposit. Carbonate alteration is dominated by calcite and ankerite with lesser dolomite and traces of siderite also present. Although the limits of alteration have not been defined, the mineralized zone extends along strike for more than 3 km.

Gold is primarily restricted to quartz veins, although low-grade gold levels (~1 ppm) are known from some wall rocks (both slate and metawacke). Associated sulphide minerals are arsenopyrite, pyrrhotite, galena, chalcopyite and pyrite with minor sphalerite. Carbonates, biotite, chlorite and minor muscovite are the dominant gangue minerals in the quartz veins.

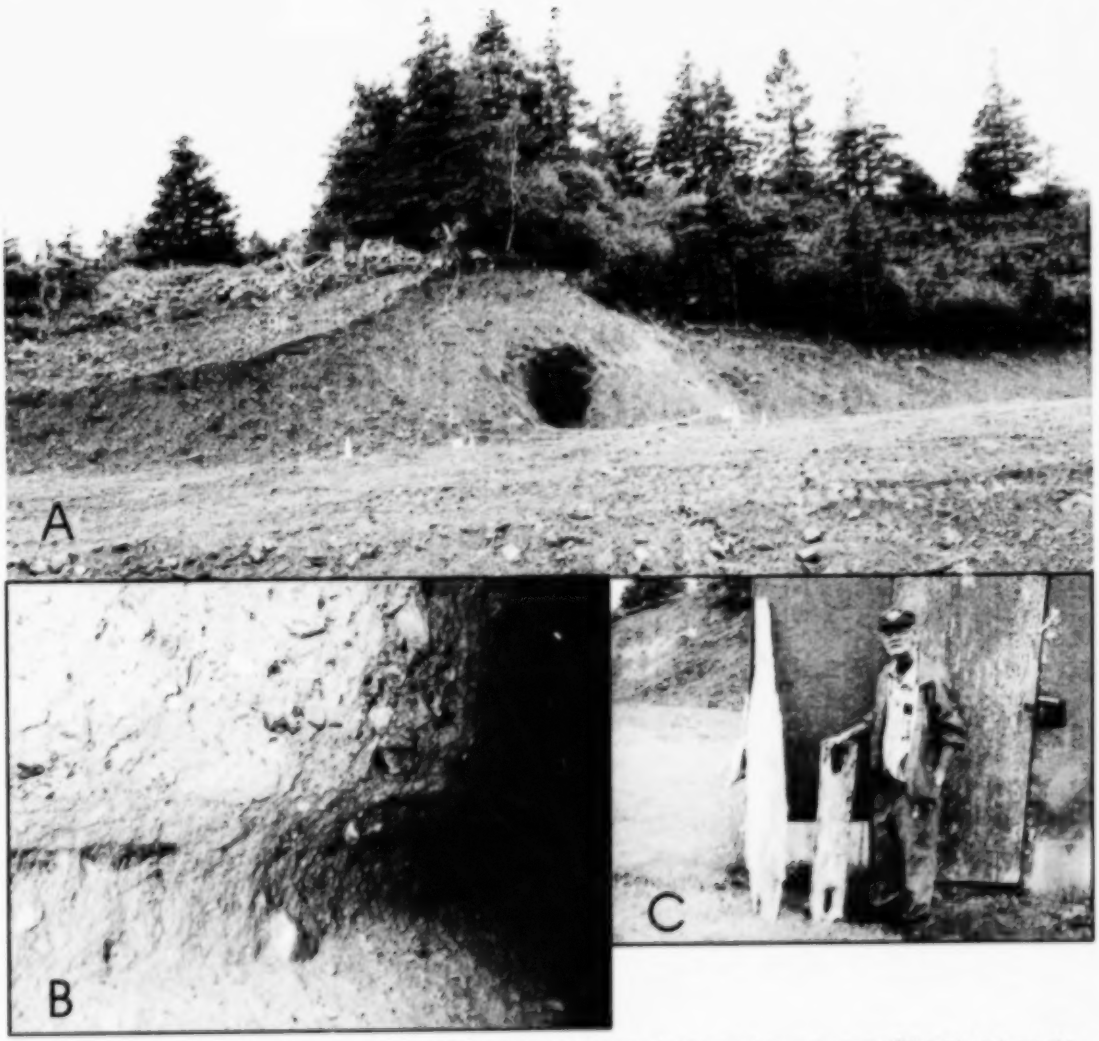


Figure 2. (A) view of the Tangier till section and the adit. (B) Close-up of the lower Lawrencetown Till (with pink granite boulder) and the upper cobbly Beaver River Till on the adit walls. (C) Wood artifacts recovered from inside the adit by Graham Cooper of Tangier (in photo).

Methods

In order to assess the economic viability of gold in till, the Quaternary section near the Tangier adit was sampled in five discreet vertical sections, using an excavator. All the sections are overlain by a well-developed soil horizon, ensuring that the section was *in situ*. Twenty-eight ~10 kg till samples were obtained from the five sections (Fig. 3). These samples were evaluated for free gold content by Overburden Drilling Management Limited (ODM). The samples were screened to separate the +2.00 mm size fraction, then tabled to obtain a crude heavy mineral concentrate (HMC). The table feed was then further enriched using a heavy liquid separation (s.g. 3.3 g/cm^3). Gold grains were counted from the heavy mineral separates, classified into size and shape categories, and an estimated gold grade was reported based on the size and number of gold grains in the sample.

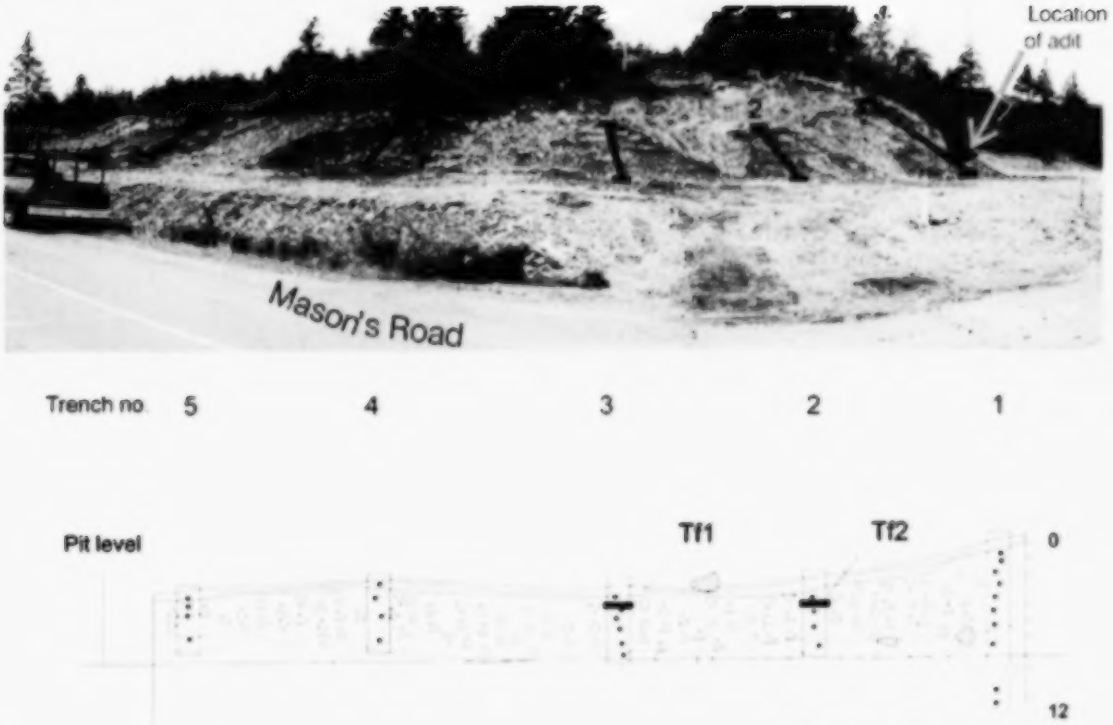


Figure 3. Schematic section and photograph of the Tangier till section. Twenty-eight samples (10 kg each) were obtained, both laterally and vertically in the till section.

The gold grades calculated for the HMCs were then 'normalized' to a bulk grade by multiplying the HMC grade by the weight dilution ratio of the HMCs, divided by the wet bulk table feed. The clast fraction (<2 mm) was subdivided by rock type and counted.

Two of the five trenches (T1 and T2) were channel sampled from near top to bottom and then processed through a sluice (see Mills *et al.*, this volume). For an evaluation of bulk till gold content, splits of all till samples in the Beaver River Till from Trench 1 (Fig. 3) were combined

and processed for a heavy mineral separate at ODM, then analyzed by fire assay at Activation Laboratories in Ancaster, Ontario. This HMC gold assay was also normalized to a bulk grade by the weight ratio method described above. A second bulk channel sample from Trench 2 was obtained using an excavator and processed by Kuryluk Developments Inc. using a Kuryluk hydraulic separator (described in Stea *et al.*, 1993) to get a more quantitative estimate of placer grades and assess the efficiency of the sluice (Mills *et al.*, this volume, p. 61-67). The Trench 2 bulk sample was dried, weighed and separated into three main size fractions for further analyses (>10 mesh; 2 mm; <20 mesh>100 mesh; 0.15 mm ; <100 mesh). The >10 mesh (gravel) size fraction was crushed to <230 mesh (0.063 mm) and a portion retained for gold geochemical analysis. The <20 - >100 mesh (sand) fraction was processed through a Kuryluk separator for heavy mineral separates, later analyzed for gold. The <100 mesh size fraction was further sieved to <230 mesh (silt+clay) for eventual gold geochemical analysis. Gold analyses of the Trench 2 samples were conducted using fire assay atomic absorption (analyses by the Mineral Engineering Centre, Dalhousie University).

The till section was mapped in detail and two standard till fabric analyses (e.g. Evenson, 1971) were completed to evaluate the flow directions of the ice sheet that formed the gold-bearing surface till. In the Tangier area several new striation sites were mapped (Fig. 1), also indicating flow directions of the last ice sheets to have eroded the vein arrays of the Tangier Gold District (Fig. 1).

Tangier Till Section

The section is located ~0.3 km south of Highway 7 on Mason's Road (Fig. 3). The pit face is part of a south-sloping hill that was excavated for road fill. The section is approximately 100 m wide and 5-10 m in height, with a mature soil profile developed at the top of the exposure.

Stratigraphy

The section revealed two Quaternary till units resting on Cambro-Ordovician metasandstone of the Meguma Group. The lower Quaternary unit is a 3-4 m thick, greyish-brown to reddish-brown, sandy to silty diamicton termed the Lawrencetown Till, overlain by a blue-grey, stony, sandy till termed the Beaver River Till (Williams *et al.*, 1984). Bedrock was encountered at a depth of 4 m below Trench 1 (Figs. 3, 4). The main gold-bearing unit is the Beaver River Till, which varies from 3 to 5 m thick across the section. It contains a predominance of locally derived, Meguma Group metasedimentary clasts (metagreywacke, metasiltstone, slate), including quartz vein material, and lesser amounts (< 5%) of granite boulders and pebbles derived from the Musquodoboit Batholith ~4 km to the north. The concentrations of granite erratics increase markedly (~ 40-50%) in the boulder mantle at the top of the section, but erratics are rare in the till just beneath.

Till fabric measurements on pebble long-axes from Trench 2 and Trench 3 in the Beaver River Till produced weak, girdling fabrics with an east-west trend and no discernable plunge direction (Fig. 4). These fabrics are nearly perpendicular to the flow directions, as implied by granite clast dispersal (south to southeast) and local bedrock striations (south to southeast - Fig. 1). The discrepancy between fabric and other ice flow indicators may be attributed to compressive ice flow, as discussed later.

Regional Ice Flow Directions

Rock outcrops in the vicinity of the gold district (Fig. 1) showed two sets of glacier striations. An early set of striae trending 151° is preserved in bevelled facets on the metagreywacke surface. A later, predominant set of striations on the upper surface trends 162-167°. The earlier set likely relates to the earliest southeastward Wisconsinan ice flow in the area, termed the Caledonia Phase, whereas the later set relates to formation of the ice divide over Nova Scotia and southeastward ice flow during the Scotian Phase (Stea, 2004).

Gold Distribution in the Tangier Till Section

The sampling results of the Tangier till section are shown graphically in Figure 5 and in tabular form in Tables 1-4. The highest concentrations are in the upper Beaver River Till which varies from 89 to

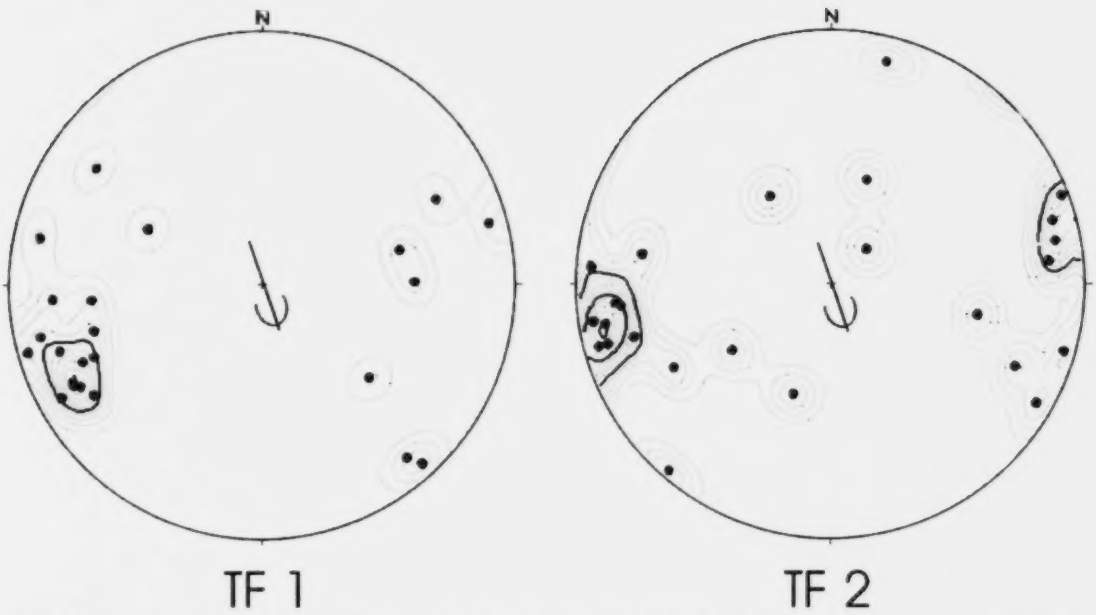


Figure 4. Lower hemispheric Schmidt net projections of the trend and plunge of the long axes of 25 clasts at two sites from the Tangier till section (Fig. 3). The symbols indicate the direction of ice flow (SE) as determined by glacial striations and clast provenance.

657 individual gold grains per sample, translating to a calculated grade of 13 to 455 ppm for the heavy mineral separates, respectively (Table 1). Grades normalized to the weight of wet table feed ranged throughout the section from 6 to 689 ppb (<0.005-0.02 oz./ton) with an average of 75 ppb. Sample 8 in Trench 1 had the highest gold count (657) and also contained the largest nugget, with dimensions of (length) 0.71 mm x (width) 0.6 mm x (thickness) 0.4 mm (Table 3). Gold assays calculated from gold grain counts must be considered as minimum levels only because of the counting method used to establish gold content. Gold tied up in sulphides and in rock fragments was not evaluated by the ODM method.

The gold levels in all trenches (Fig. 5) increase up section in the Beaver River Till to a peak within 1-3 m of the surface. It is important to note that soil samples revealed little visible gold (0-1 grains) in spite of elevated levels in the tills just beneath. A down-ice trend of decreasing overall gold levels was observed from Trench 1 (proximal to gold district) to Trench 5 (distal). The Beaver River Till contains almost exclusively Meguma metasedimentary clasts, varying from 95-99%. Granite and quartz clasts remain below 1% in the sections, except at the contact with the Lawrencetown Till (5% granite) and at the top of the section where the ablation boulder mantle consists of between 40% and 50% granites.

Contrasting with the auriferous Beaver River Till, the underlying red Lawrencetown Till displayed significantly lower gold counts, ranging from 4-30 grains per sample with a mean of 14 (Fig. 5; Table 1) and with normalized grades of 0.02-1 ppb. These lower gold levels correspond to much lower percentages of Meguma metasedimentary rocks (35-60%) compared to the Beaver River Till (Table 1).

Bulk Sampling Results

Seven samples (111-04-4 to 111-04-10 TR1) in Trench 1, weighing 79 kg, were individually processed for heavy mineral concentrates then combined and assayed. The bulk assay result of 98 700 ppb was normalized to 202 ppb (0.007 oz./ton) using the total wet weight of table feed (28.7 kg). This concentration is significantly higher than the bulk average derived from gold counts (163 ppb-Fig. 5).

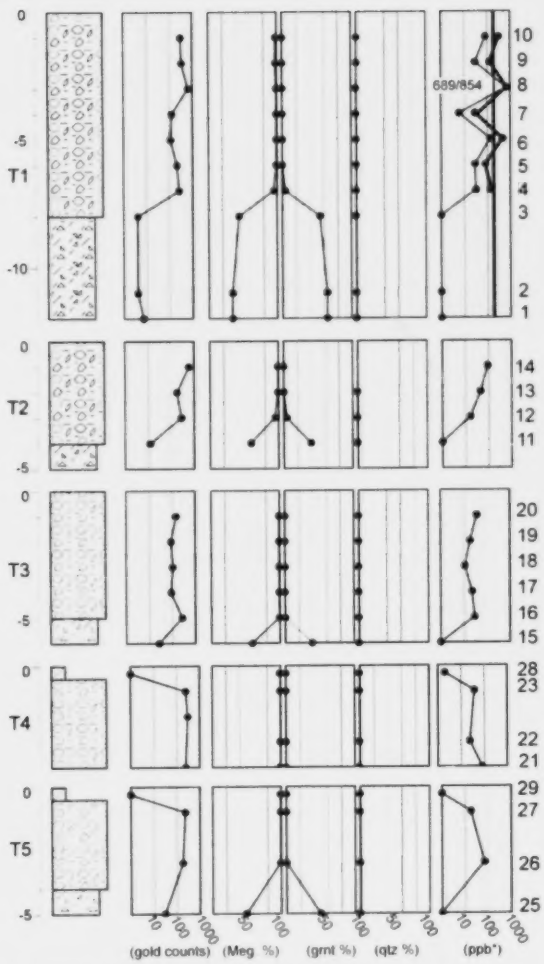


Figure 5. Stratigraphy, pebble lithology and gold distribution in trenches 1-5. Gold grain counts and parts per billion (ppb) are presented using a logarithmic scale. Gold abundance (ppb) was calculated using the estimated grades from grain counts and the total weight (wet) of table feed (Table 2). The heavy line curve to the right of the gold abundance curve in Trench 1 represents "corrected" grades based on the ratio of the average gold abundance in Trench 1 determined by fire assay and calculated by grain counts (202 ppb/ 163 ppb=1.24). The solid line represents the average corrected gold grade in Trench 1 (202 ppb). Sample numbers (Table 1) on the right.

A 109 kg bulk sample from Trench 2 was processed and analyzed as described in the Methods section. Gold analyses were obtained from heavy mineral separates, from a crushed portion of the coarse gravel fraction, and from a sieved portion of the fine fraction (Table 4). Approximately 50% of the sample was gravel-sized (granule, pebble and cobble; +10 mesh), ~ 40% sand-sized material (-20+100 mesh), and the remaining 10% in the fine fraction (silt +clay). Interestingly, high levels (185-350 ppb/0.005-0.01 oz./ton) were obtained from the coarse fraction (+10 mesh) which was crushed to -230 mesh. The gold level obtained by fire assay of hydrostatic gold separates of the sand fraction was 170 ppb (0.005 oz./ton; Table 4). The grades calculated from gold grain counts of individual samples in Trench 2 averaged 58 ppb, significantly lower than the assay grades of a bulk sample of the same trench (351 ppb).

The sieved, fine fraction of the bulk sample recorded the lowest gold levels (8-125 ppb). The variability between sample duplicates (Table 4) can be ascribed to the nugget effect (cf. MacEachern and Stea, 1985).

Discussion

Genesis of the Beaver River Till

The Beaver River Till (Grant, 1980; Finck and Stea, 1995) makes up a landscape unit termed the stony till plain (Stea *et al.*, 1992), characterized by irregular, hummocky topography or ribbed moraine and large slate, quartzite or granite boulders (from <1 m up to 20 m in diameter) strewn on the surface. This till facies was originally interpreted as an ablation till, based on its looseness and coarse texture (Nielsen, 1976).

Beaver River Till is dominated by a single local bedrock-derived, clast lithology, with percentages generally > 90%. Deviations from this idealized clast lithology reflect reworking from underlying drumlin tills or the proximity of variable up-ice bedrock units. Clast lithology of the Beaver River Till can be used as an accurate tool to map bedrock geology (MacDonald and Horne, 1987).

The renewal distance, as defined by Peltoniemi (1985), is the distance down-ice over bedrock contacts in which the proportion of a new rock type increases in the till from 0% to 50%. Renewal distances calculated for the Beaver River Till average between 0.2 and 1 km (Stea and Finck, 2001). These extremely low renewal distances (e.g.

Table 1. Gold grain counts and shapes, and calculated assay concentrations of the heavy mineral concentrates.

Sample Number	Till Type	Number of visible gold grains				Weight (g) HMC	Calculated gold (ppb)
		Total	Reshaped	Modified	Pristine		
111-04-1TGR-TR-1	LT	7	2	4	1	14.4	193
111-04-2TGR-TR-1	LT	4	4	0	0	19.2	29
111-04-3TGR-TR-1	LT	4	1	3	0	14.0	224
111-04-4TGR-TR-1	BRT	259	20	77	162	17.2	7513
111-04-5TGR-TR-1	BRT	207	2	25	180	7.2	15992
111-04-6TGR-TR-1	BRT	110	1	1	108	2.6	15371
111-04-7TGR-TR-1	BRT	125	1	2	122	3.8	5235
111-04-8TGR-TR-1	BRT	657	0	2	655	5.6	455344
111-04-9TGR-TR-1	BRT	345	0	6	339	13.8	12567
111-04-10TGR-TR-1	BRT	314	1	2	311	8.4	49722
111-04-11TGR-TR-2	LT	12	2	0	10	19.4	300
111-04-12TGR-TR-2	BRT	279	7	68	204	16.7	4922
111-04-13TGR-TR-2	BRT	178	4	43	131	11.0	20806
111-04-14TGR-TR-2	BRT	599	12	125	462	10.6	47867
111-04-15TGR-TR-3	LT	26	11	6	9	18.5	183
111-04-16TGR-TR-3	BRT	266	12	55	199	20.1	8779
111-04-17TGR-TR-3	BRT	89	14	30	45	5.2	13600
111-04-18TGR-TR-3	BRT	105	19	31	55	6.5	7195
111-04-19TGR-TR-3	BRT	89	2	12	75	7.6	10837
111-04-20TGR-TR-3	BRT	146	5	31	110	8.7	17100
111-04-21TGR-TR-4	BRT	245	10	60	175	12.1	33155
111-04-22TGR-TR-4	BRT	303	1	23	279	12.2	10266
111-04-23TGR-TR-4	BRT	249	2	42	205	12.1	15567
111-04-25TGR-TR-5	LT	30	1	4	25	6.7	456
111-04-26TGR-TR-5	BRT	177	6	25	146	11.2	28116
111-04-27TGR-TR-5	BRT	233	0	28	205	8.9	8864
28SoilTR-4		1	0	1	0	0.1	3731
29SoilTR-5		0	0	0	0	0.2	0

Scandinavian tills average 5-20 km; Peltoniemi, 1985) are indicative of low-velocity basal ice conditions in proximity to an ice divide (Stea *et al.*, 1989). The angular nature, lack of striae on the clasts, and the predominance of clast modes, suggest that quarrying and fracturing are dominant mechanisms in the formation of the Beaver River Till, rather than abrasion. Low sliding velocities are implied by the negligible dispersal, reinforcing the idea that these tills were deposited near or under the Scotian Ice Divide across the axis of Nova Scotia (Stea, 2004). These can be considered 'immature' tills (cf. Dreimanis and Vagners, 1971), implying that they were formed in a relatively short period of time and not given the chance to develop a fine-grained matrix component through comminution and abrasion. These stony local tills are common near former ice centres in central New Brunswick (Broster *et al.*, 1997) and throughout the shield areas of Canada (Dredge, 1983).

This lithologic discrepancy of the granite-dominated ablation boulder mantle and the locally derived underlying till can be attributed to the process of long-distance, englacial transport of these large boulders. In fact, the layer of surface boulders likely represents a matrix-less ablation till as described by Shilts (1981). The lack of matrix in the surface 'ablation till' also reflects the short-lived activity of the local ice divide. Prospectors must also consider the fact that the boulder cover of the stony till plain is usually farther travelled than the underlying Beaver River Till. An auriferous

Table 2. Sample weights, weights of heavy mineral concentrates, and clast percentages.

Sample Number	Weight (kg wet)				<2.0 mm Table Concentrate Weight (g dry)					Clast percentages (>2mm)		
	Total (wet)	Table Split	<2mm clasts	Table Feed	Total	Heavy Liquid Separation (S.G. 3.3)				Meguma meta-ss	Granite	Quartz
						Lights	Heavy minerals (HMC)					
							Total	Non Mag	Mag			
111-04-1TGR-TR-1	16.3	15.5	3.7	11.8	501.7	485.8	15.9	14.4	1.50	35	65	Tr
111-04-2TGR-TR-1	17.3	16.5	3.4	13.1	494.9	474.1	20.8	19.2	1.60	35	65	Tr
111-04-3TGR-TR-1	9.1	8.3	1.9	6.4	314.2	298.9	15.3	14.0	1.30	45	55	Tr
111-04-4TGR-TR-1	10.7	9.9	5.8	4.1	444.5	426.4	18.1	17.2	0.90	95	5	Tr
111-04-5TGR-TR-1	9.6	8.8	4.8	4.0	276.5	268.9	7.6	7.2	0.40	100	Tr	Tr
111-04-6TGR-TR-1	11.1	10.3	7.3	3.0	241.2	238.4	2.8	2.6	0.20	100	Tr	Tr
111-04-7TGR-TR-1	9.9	9.1	5.9	3.2	369.5	365.4	4.1	3.8	0.30	100	Tr	Tr
111-04-8TGR-TR-1	12.1	11.3	7.6	3.7	353.4	347.3	6.1	5.6	0.50	100	Tr	Tr
111-04-9TGR-TR-1	10.8	10.0	4.3	5.7	249.9	235.4	14.5	13.8	0.70	100	Tr	Tr
111-04-10TGR-TR-1	11.8	11.0	6.0	5.0	285.2	276.5	8.7	8.4	0.30	100	Tr	Tr
111-04-11TGR-TR-2	11.5	10.7	1.5	9.2	372.7	351.7	21.0	19.4	1.60	60	40	Tr
111-04-12TGR-TR-2	12.5	11.7	6.4	5.3	310.3	292.6	17.7	16.7	1.00	95	5	Tr
111-04-13TGR-TR-2	13.0	12.2	7.0	5.2	322.6	310.6	12.0	11.0	1.00	100	Tr	Tr
111-04-14TGR-TR-2	14.7	13.9	8.3	5.6	311.7	300.5	11.2	10.6	0.60	100	Tr	Tr
111-04-15TGR-TR-3	10.3	9.5	2.6	6.9	368.8	348.8	20.0	18.5	1.50	60	40	Tr
111-04-16TGR-TR-3	12.5	11.7	5.5	6.2	465.8	444.4	21.4	20.1	1.30	100	Tr	Tr
111-04-17TGR-TR-3	8.4	7.6	4.5	3.1	208.6	203.1	5.5	5.2	0.30	100	Tr	Tr
111-04-18TGR-TR-3	11.6	10.8	6.6	4.2	330.4	323.5	6.9	6.5	0.40	100	Tr	Tr
111-04-19TGR-TR-3	10.9	10.1	5.7	4.4	311.5	303.4	8.1	7.6	0.50	100	Tr	Tr
111-04-20TGR-TR-3	11.5	10.7	6.7	4.0	327.1	317.6	9.5	8.7	0.80	100	Tr	Tr
111-04-21TGR-TR-4	11.2	10.4	5.4	5.0	296.3	283.1	13.2	12.1	1.10	100	Tr	Tr
111-04-22TGR-TR-4	13.0	12.2	7.0	5.2	344.2	331.2	13.0	12.2	0.80	100	Tr	Tr
111-04-23TGR-TR-4	8.8	8.0	3.1	4.9	288.3	275.3	13.0	12.1	0.90	100	Tr	Tr
111-04-25TGR-TR-5	4.4	3.6	0.8	2.8	142.9	135.7	7.2	6.7	0.50	50	50	Tr
111-04-26TGR-TR-5	10.7	9.9	5.2	4.7	420.2	408.2	12.0	11.2	0.80	100	Tr	Tr
111-04-27TGR-TR-5	11.4	10.6	6.2	4.4	319.1	309.6	9.5	8.9	0.60	100	Tr	Tr
28SoilTR-4	1.0	0.7	0.5	0.2	55.1	55.0	0.1	0.1	0.02	100	0	Tr
29SoilTR-5	0.8	0.5	0.3	0.2	109.7	109.5	0.2	0.2	0.02	100	0	Tr

Table 3. Size distribution of gold in till sample 8 with the highest gold counts and assay level.

111-04-8TGR-TR-1 visible gold grains			
Dimensions (microns)			
Thickness	Width	Length	Total grains
2	10	10	53
4	15	25	142
5	25	25	181
8	25	50	133
10	50	50	68
13	50	75	31
15	50	100	10
18	50	125	3
15	75	75	9
18	75	100	5
20	75	125	6
22	75	150	3
22	100	125	1
25	100	150	4
100	100	250	1
27	125	150	1
150	250	250	1
59	300	375	1
100	300	600	1
200	375	375	1
300	500	600	1
400	600	700	1
			657

quartz vein in a surface boulder, for example, may be derived from a source up to 4 km away, whereas the underlying basal till may have a much more proximal source, as demonstrated in this study.

The transverse fabrics obtained in the till at Tangier (Fig. 5) are not uncommon in basal melt-out tills, especially in areas of compressive ice flow (Boulton, 1970). The compressive flow may have been induced as the ice was forced to override a drumlin obstacle composed of Lawrencetown Till just south of Tangier. Mallinson (1988) described the results of till fabric analysis from two trenches from the Dufferin Gold District in which he obtained easterly and southeasterly modes (63°-125°) in the Beaver River Till, also nearly perpendicular to regional ice flow directions.

The lack of comminution of the Beaver River Till is aptly demonstrated not only by the angular, unstriated clasts but by the pristine or relatively unabraded gold grains (Fig. 6; Table 3) that make up the vast majority of gold grains in the till samples. A transport distance of <500 m is indicated by the shape distribution of these gold grains (DiLabio, 1990).

The Concept of Potentially Mineable Till Down-ice of Gold Districts

The increased concentration of gold grains and auriferous debris at the top of the Tangier trench sections is consistent with the up-section migration of mineralized debris from a lode source in a classic dispersal plume (Fig. 6; e.g. Miller, 1984). The decrease in concentration of gold in till away from the vein sources in both section and plan-view follows an exponential law (Klassen, 2001). Goodwin (this volume, p. 15-26) has obtained gold grain counts in surface till from a transect across the Beaver Dam Gold District that verify this property of gold dispersal. He observed a rapid increase in levels across the gold district to a maximum (161 grains), immediately down-ice of the last known vein. The gold counts then exhibit a sharp exponential decrease down-ice from the highest concentration levelling out at 25 grains 1.4 km from source. Similar patterns of exponential decrease were observed in different size fractions analyzed by fire assay at Beaver Dam and other Nova Scotia gold districts (DiLabio, 1982; Coker *et al.*, 1988).

The evaluation of a potential economic window of gold-bearing till down-ice of the Tangier Gold District must be based on the pattern of exponential decrease in gold levels from the source. Since there is no dispersal curve for the Tangier Gold District, the dispersal curve for the Beaver Dam district will be used as a proxy. Figure 7 shows the increase and decrease of gold grains down-ice of Beaver Dam, with gold grain counts normalized to 100%. This normalization procedure produces an idealized dispersal curve which to some extent compensates for variations in vein thickness and gold content inherent in the gold districts. The Tangier till section is located ~300 m down-ice of the last gold-bearing veins at Tangier, which corresponds to the rapidly decreasing slope of the exponential dispersal curve (Fig. 7). Gold levels should therefore increase in the Beaver River Till as one approaches the gold-bearing veins of the Tangier

Table 4. Fire assay gold analyses from Trench 1 and 2, bulk channel samples. The bulk assay* was normalized back to the weights of sand feed producing the heavy mineral concentrates. The bulk assay was calculated by multiplying the HMC assay by the weight dilution factor (HMC/table feed). In Trench 2 duplicate analyses are from analytical splits of the prepared sample.

Bulk channel sample (samples 4-10T1) Trench 1 (76 kg)			
Size Fraction	weight (g)	Analyses (ppb)	
table feed/ HMC bulk assay	28 700/58.6	98 700 202*	
Bulk channel sample Trench 2 (109.266 kg)			
Size Fraction	dry weight (g)	Analyses (ppb)	
+10 mesh (gravel)	55 000	185	350
sand feed/ HMC bulk assay	53 176/ 7.7	2 424 000 351	
<230 mesh (silt + clay)	1 090	8	125

Gold District (Fig. 7). The bulk assay from Trench 1 (0.007 oz./ton) should, therefore, increase by ~30% to a peak of 0.01 oz./ton then decrease again with proximity to the lode deposit. The average grade calculated under this economic window would be ~0.0085 oz./ton.

There are obviously not enough data in the second and third dimension to calculate tonnages in the down-ice till window, as defined in Figure 1, but "potential" tonnages can be extrapolated using two assumptions:

(1) the gold content of till follows the exponential dispersal law down-ice of the gold district; and

(2) gold levels in the till are consistent both vertically and laterally along strike.

The first assumption is undoubtedly valid because the patterns of down-ice dispersal have been verified at several gold districts (e.g. Coker *et al.*, 1988).

The second assumption requires further testing, as the gold content in the vein systems of the Tangier Gold District is highly variable along strike (Malcolm, 1929). The Tangier section is down-ice of the main producing gold veins north of the town of Tangier, so grades in till are likely to decrease to the east (Fig. 1). Gold anomalies in previous surveys (Dimmell, 1983) down-ice from the eastern portion of the Tangier district, however, verify that gold is found in till in the dispersal zone right across the district. Eroded gold debris from lode sources tends to migrate up-section (Fig. 6), as demonstrated in the increases in gold content towards the tops of trenches 1-5. These dispersal plumes will be stacked one on top of another in the case of multiple vein sets, producing a thicker gold-enriched till section. This may be the case at Tangier and other similar, larger districts where gold was extracted from multiple vein systems.

The bulk testing results from Trench 2 (Table 4) revealed that the crushed, coarse fraction of till contained comparable levels of gold to the hydrostatically separated gold, approaching 0.01 oz./ton. It is important to remember that till is not a 'placer' deposit, that is material hydro-dynamically sorted by running water. Till is essentially the product of incomplete crushing of the lode source, with the addition of adjacent bedrock as a filler, and transportation en masse by glacier ice. Crushing and heap leaching of till to extract gold must be considered when evaluating till as an ore source. This method proved effective at Moose River at the turn of the Twentieth Century.

Tonnages in the model window are calculated by determining the volume of the zone depicted in Figure 1 (Length x Width x Thickness), converted to weight (metric tonnes) using a standard bulk density (weight per unit volume) value for glacial till of 2.0 tonnes (t)/m^3.

V=L x W x T
T= the average thickness of the Beaver River Till (4 m)
L= strike length of the gold-producing veins (Fig. 1; 2500 m)
W= economic 'window' width under the dispersal curve (Fig. 1; 300 m)

Volume = 3×10^6 cubic metres
Weight = volume x bulk density
= 3×10^6 m^3 x 2.0 t/m^3
= 6×10^6 t

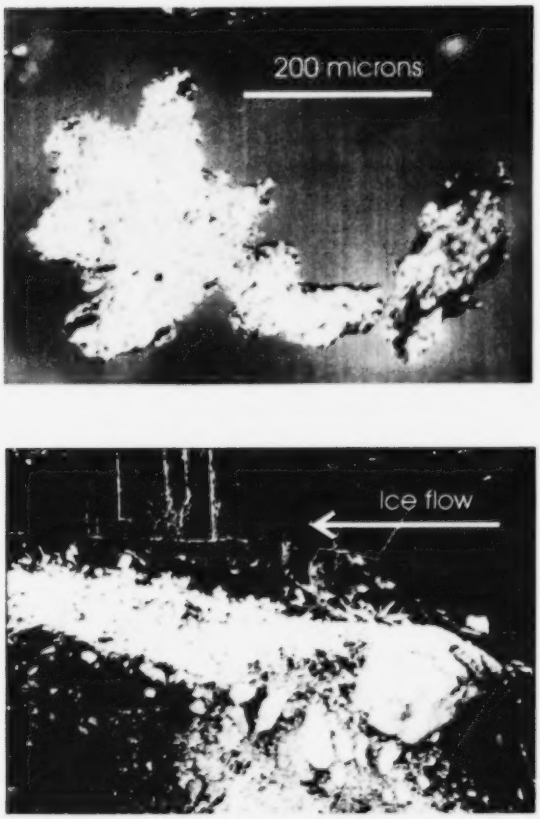


Figure 6. (Top) 'Pristine' gold grain from the Tangier till section (length 400 microns). (Bottom) Dispersal plume of quartz in the Beaver River Till at the Beaver Dam Gold District. Note how the quartz debris is distributed up-section and down-ice of the vein source.

Heap leach or bulk extraction till model (0.01 oz./ton)

$= 6 \times 10^6$ tonne x 0.01 oz./tonne

$=$60,000 oz.

Placer till model (0.0085 oz./tonne) (calculated from sand fraction $=$ 50% of the total weight):

$= 6 \times 10^6$ tonne/2 x .0085 oz./tonne

$=$ 25,500 oz.

These calculations are only meant to serve as a theoretical model for the potential of till as a viable gold deposit. They cannot be used as an actual resource or reserve calculation.

Recommendations

In essence, till deposits south of the gold districts are made up of crushed, gold-bearing rock that was transported just south of the mines and dumped by a glacier. They may be considered as tailings piles that have not been processed. In order to evaluate the validity of our till mining model explorationists should undertake further testing in the potentially economic zone down-ice of gold districts. In the Tangier District, unfortunately, much of the gold-bearing till underlies the town, but the principles established in this study could be applied along strike of the main Blueberry Hill deposit, or in similar gold districts elsewhere. The economic window of gold-bearing till may be wider or narrower depending on the grades, strike lengths, numbers and widths of the gold vein systems (see Horne *et al.*, this volume). Evaluation of the down-ice till deposits is best done by excavation of till in the window and bulk sampling. In some gold districts previously excavated borrow pits are already available for sampling. A sluice can be set up in some areas as a means of further exploration and gold recovery (see Mills *et al.*, this volume). Extraction of gold by crushing and heap leaching of till may be considered, as well as the potential for sand and gravel by-products from a larger scale operation.

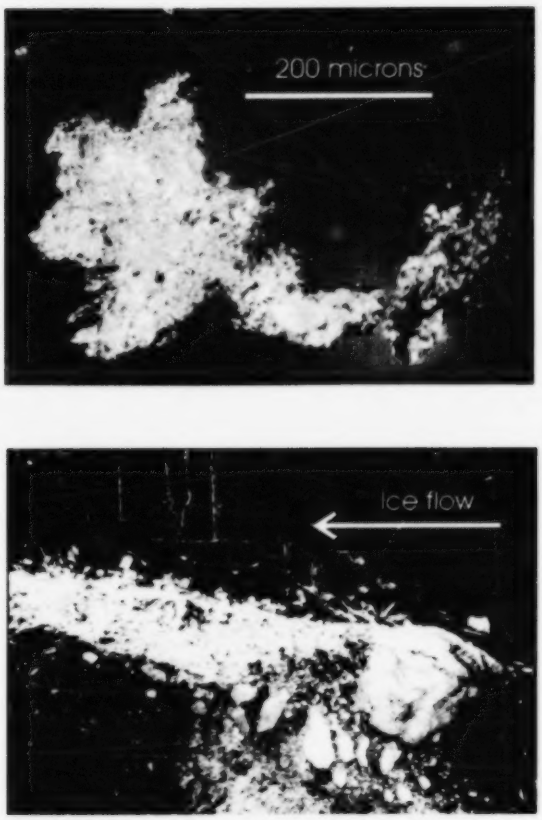
References

Boulton, G. S. 1970: On the origin and transport of englacial debris in Svalbard glaciers: Journal of Glaciology, v. 9, no. 56, p. 213-229.

Broster, B. E., Munn, M. D. and Pronk, A. G. 1997: Inferences on glacial flow from till clast dispersal: Waterford area, New Brunswick: Géographie physique et Quaternaire, v. 51, p. 29-39.

Chalmers, R. 1895: Report on the surface geology of eastern New Brunswick, northwestern Nova Scotia and a portion of Prince Edward Island: Geological Survey of Canada, Annual Report 1894, 1:7: pt. M, 144 p.

Coker, W. B., Sexton, A., Lawyer, I. and Duncan, D. 1988: Bedrock, till and soil geochemical signatures at the Beaver Dam gold deposit, Nova Scotia, Canada: *in* Prospecting in Areas of Glaciated Terrain, 1982, eds. D. R. MacDonald and K. A. Mills: Canadian Institute of Mining and Metallurgy.



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References

Boulton, G. S. 1970: On the origin and transport of englacial debris in Svalbard glaciers; Journal of Glaciology, v. 9, no. 56, p. 213-229.

Broster, B. E., Munn, M. D. and Pronk, A. G. 1997: Inferences on glacial flow from till clast dispersal: Waterford area, New Brunswick; Géographie physique et Quaternaire, v. 51, p. 29-39.

Chalmers, R. 1895: Report on the surface geology of eastern New Brunswick, northwestern Nova Scotia and a portion of Prince Edward Island; Geological Survey of Canada, Annual Report 1894, 1:7: pt. M, 144 p.

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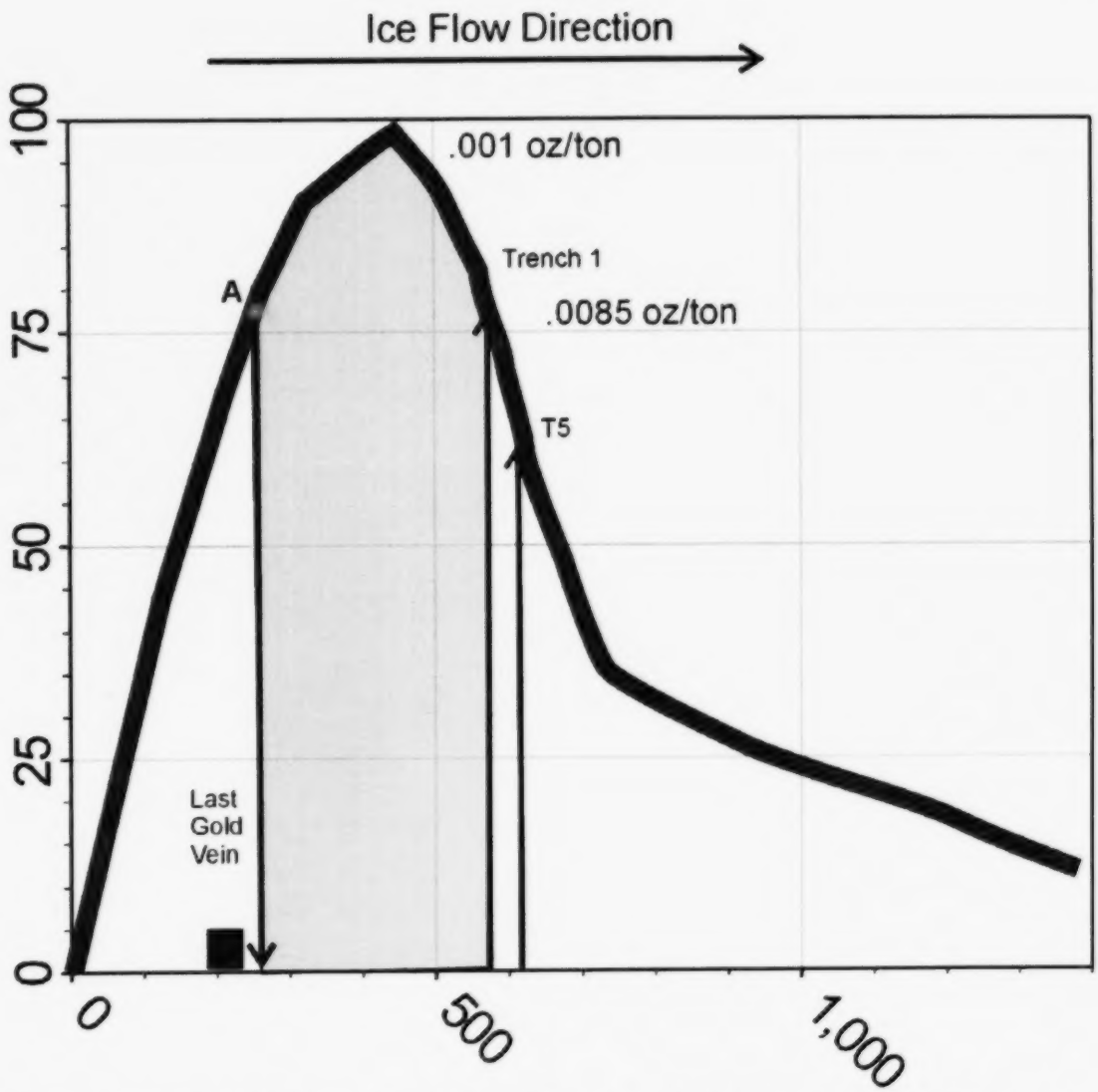

Figure 7. Dispersal curve of the Beaver Dam gold district (Goodwin, this volume), normalized to 100%. This curve is transposed to the Tangier Gold District and the location of the Tangier section is plotted on the curve. The area under the curve is a potential economic 'window' of gold in till.

DiLabio, R. N. W. 1982: Drift prospecting near gold occurrences at Onaman River, Ontario, and Oldham, Nova Scotia; *in* Geology of Canadian Gold Deposits, eds. R. W. Hodder and W. Petruk; Proceedings of the CIM Gold Symposium, Special Volume; Canadian Institute of Mining and Metallurgy, v. 24, p. 261-266.

DiLabio, R. N. W. 1990: Classification and interpretation of the shapes and surface textures of gold grains from till on the Canadian Shield; *in* Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p. 61-65.

Dimmell, P. M. 1983: Gold, Tangier, Halifax County, Nova Scotia; Report on geological mapping, a till geochemical survey and

recommendations for exploration of placer gold deposits; Nova Scotia Department of Natural Resources, Assessment Report ME 11D15A 21-H-67(21).

Dreimanis, A. and Vagners, U. 1971: Bimodal distribution of rock and mineral fragments in basal tills; *in* Till: A Symposium, ed. R. P. Goldthwait; Ohio State University Press, p. 237-250.

Dredge, L. A. 1983: Surficial geology of the Sept Iles area, Quebec north shore; Geological Survey of Canada, Memoir 408, Ottawa, Ontario, 40 p.

Grant, D. R. 1980: Quaternary stratigraphy of southwestern Nova Scotia: glacial events and sea-level changes; Geological Association of Canada and Mineralogical Association of Canada, Guidebook, 63 p.

Evenson, E. B. 1971: The relationship of macro and microfabric of till and the genesis of glacial landforms in Jefferson County, Wisconsin; *in* Till: A Symposium, ed. R. P. Goldthwait; Ohio State University Press, p. 345-366.

Finck, P. W. and Stea, R. R. 1995: The compositional development of tills overlying the South Mountain Batholith; Nova Scotia Department of Natural Resources, Mines and Minerals Branch, Paper 95-1, 51 p.

Klassen, R. A. 2001: A Quaternary perspective on geochemical exploration in glaciated terrain; *in* eds. .B. McClenaghan, M. B. Bobrowski, P. T. Hall and S. J. Cook, Geological Society of London, Special Publication 185, p. 1-17.

MacDonald, M. A. and Horne, R. J. 1987: Geological map of Halifax and Sambro (NTS sheets 11D/05 and 1D/12), Nova Scotia; Nova Scotia Department of Mines and Energy, Map 87-06, scale 1:50 000.

MacEachern, I. J. and Stea, R. R. 1985: The dispersal of gold and related elements in tills and soils at the Forest Hill Gold District, Guysborough County, Nova Scotia; Geological Survey of Canada, Paper 85-18.

Malcolm, W. 1929: Gold fields of Nova Scotia; Geological Survey of Canada, Memoir 156, 253 p.

Mallinson, T. 1988: Report on geology, geochemical surveys, geophysical surveys and trenching on Exploration Licenses #12257 and #12558, Salmon River, Nova Scotia; Nova Scotia Department of Natural Resources, Assessment Report AR88-382, 26 p.

Miller, J. K.1984: Model for clastic indicator trains in till; *in* Prospecting in Areas of Glaciated Terrain, 1984; Institute of Mining and Metallurgy, London, p. 69-77.

Mills, R. F., Stea, R. R., Smith, P. K. and Goodwin, T. A. 2005: A placer gold investigation at Tangier, Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2004, ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report ME 2005-1, p.??.

Nielsen, E. 1976: The composition and origin of Wisconsinan tills in mainland Nova Scotia; Ph. D. thesis, Dalhousie University, Halifax, Nova Scotia, 256 p.

Nova Scotia Department of Natural Resources 1887: Miscellaneous Report A-007, 1887, "The Critic"; A trip to the eastern gold districts.

Peltoniemi, H. 1985: Till lithology and glacial transport in Kuhmo, eastern Finland; Boreas, v. 14, p. 67-74.

Shilts, W. W. 1981: Surficial geology of the Lac Megantic area, Quebec; Geological Survey of Canada Memoir 397, 102 p.

Smith, P. K. 2000: The Tangier Gold Deposit (NTS 11D/15A): underground gold assay results from the Whin Vein; *in* Minerals and Energy Branch, Report of Activities 1999, eds. D. R. MacDonald and K. A. Mills; Nova Scotia Department of Natural Resources, Report ME 2000-1, p. 189-198.

Stea, R R. 2004: The Appalachian Glacier Complex in Maritime Canada; *in* Ehlers, J. and Gibbard, P. L. (eds.), Quaternary Glaciations Extent and Chronology:Part II North America; Elsevier, Amsterdam, p. 213-232.

Stea R. R., Conley, H. and Brown, Y. (compilers) 1992: Surficial geology of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Map ME 92-1, scale 1:500 000.

Stea, R. R. and Finck, P. W. 2001: An evolutionary model of glacial dispersal and till genesis in Maritime Canada; *in* B. McClenaghan, M. B. Bobrowski, P. T. Hall, and S. J. Cook, (eds.), Drift Exploration in Glaciated Terrain: Geological Society of London, Special Publication 185, p. 237-265.

Stea, R. R., Pecore, S. and Fader, G. B. J. 1993: Quaternary stratigraphy and placer gold potential of the inner Scotian Shelf; Nova Scotia Department of Natural Resources, Mines and Energy Branches, Paper 93-2, p. 62.

Stea, R. R., Turner, R. G., Finck, P. W. and Graves, R. M. 1989: Glacial dispersal in Nova Scotia: a zonal concept;. *in* R. N. W. DiLabio and W. B. Coker (eds.), Drift Prospecting; Geological Survey of Canada, Paper 89-20, p. 155-169.

Williams, G. L., Fyffe, L. R., Wardle, R. J., Colman-Sadd, S. P. and Boehner, R. C. 1985: Lexicon of Canadian Stratigraphy, Volume VI, Atlantic Region; Canadian Society of Petroleum Geologists, 572 p

Geology of the Washabuck Peninsula, Central Cape Breton Island, Nova Scotia

D. Wasylik[1], C. E. White and S. M. Barr[1]

Introduction

The Washabuck Peninsula is part of the Bras d'Or terrane (Barr and Raeside, 1989; Raeside and Barr 1990) of central Cape Breton Island (Fig. 1). Like other parts of the Bras d'Or terrane, the peninsula includes exposures of varied metamorphic and plutonic rocks surrounded by younger Carboniferous sedimentary units. The Carboniferous rocks on the peninsula are well known for their gypsum quarries and lead-zinc showings, and the presence of an abandoned gold mine and several other mineral occurrences in the older rocks (DeMont, 1991, 1992) suggest that they also have economic potential. The purpose of this project was to develop a better understanding of the distribution and field relations of rock units in the Washabuck Peninsula, with a focus on the petrological features of the pre-Carboniferous units and their comparison to equivalent units in other parts of central Cape Breton Island.

Geological Setting

Although historically most metamorphic rocks in Cape Breton Island were assigned to the George River Series or Group (e.g. Milligan, 1970; Keppie 1979), mapping and petrological studies during the past 25 years have resulted in the recognition of a number of different and in some cases unrelated metamorphic rock units which were given separate names (e.g. Raeside and Barr, 1990). Collectively, the separate metamorphic units in the Bras d'Or terrane are assigned now to either the George River Metamorphic Suite or the Bras d'Or Gneiss (Keppie, 2000). The George River Metamorphic Suite includes mainly low- to medium-grade clastic, carbonate, and volcanic rocks, whereas the Bras d'Or Gneiss consists of mainly high-grade (low-pressure, high-temperature) metamorphic rocks. Both units are intruded by ca. 565 Ma to 555 Ma plutons and less abundant Cambrian and younger plutons. These units are unconformably overlain by clastic sedimentary rocks of the Horton Group, which are in turn disconformably overlain by marine evaporite, carbonate, and clastic rocks of the Windsor Group (Keppie 2000).

Most previous work done on the Washabuck Peninsula concentrated on Carboniferous rocks. Hein *et al.* (1988) described the pre-Carboniferous rocks as "Devonian granitic and dioritic intrusive rocks, with minor gabbroic and dioritic dykes". Goudge (1934) reported a large deposit of Precambrian metamorphosed dolostone and limestone but subsequent published maps grouped the marble with a pre-Carboniferous granite unit (e.g. Lynch and Lafrance, 1996; Keppie, 2000). DeMont (1991, 1992) reported gold, silver, galena, pyrite, chalcopyrite, and sphalerite occurrences near Burnt Point (Fig. 2), hosted by quartzite, hornblende, feldspathic greywacke, and/or rhyolite tuff. He also reported occurrences of gold, silver, galena, chalcopyrite, specularite, bornite and malachite, hosted by similar rocks near Maskells Harbour. Jensen (1993, 1995a, b) reported pre-Carboniferous rocks over a wide area with gold, silver, sphalerite, galena, chalcopyrite, and pyrite

Geology of the Washabuck Area

Introduction

Geological mapping on the Washabuck Peninsula at a scale of 1:10 000 during June 2003, resulted in division of the rocks into five units: Maskells Harbour formation, Washabuck pluton, Grass Cove pluton, Horton Group (Creignish, Strathlorne and Ainslie formations), and Windsor Group (Fig. 2). Petrological studies of the pre-Horton Group rocks

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Wasylik, D., White, C. E. and Barr, S. M. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 117-128.

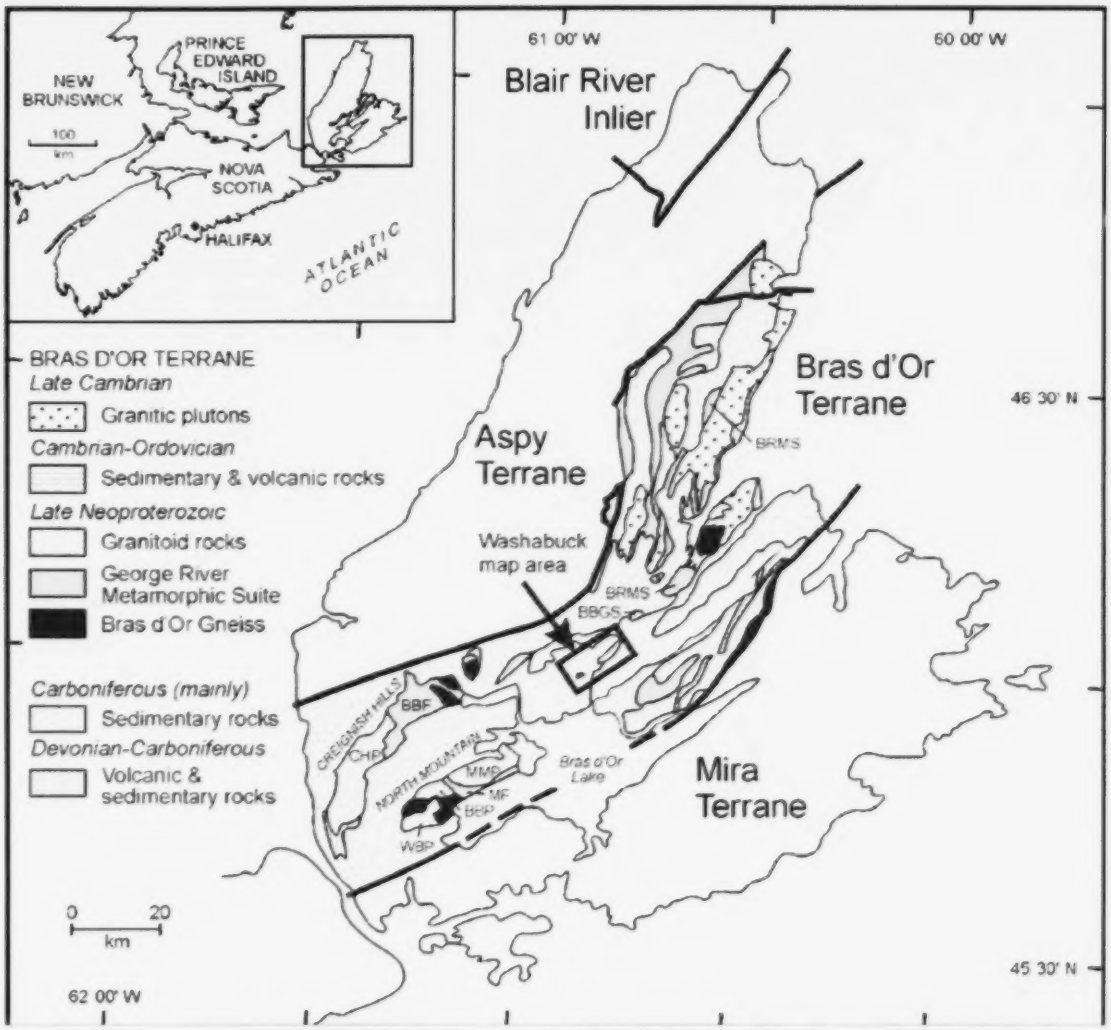

Figure 1. Location of the Washabuck Peninsula map area in the Bras d'Or terrane of central Cape Breton Island. Abbreviations: BBP, Big Brook Pluton; BBGS, Beinn Breagh Granitoid Suite; BRMS, Barachois River Metamorphic Suite; BBF, Blues Brook Formation; CHP, Creignish Hills Pluton; MF, Malagawatch Formation; MMP, Marble Mountain Pluton; WBP, West Bay Pluton.

formed the B.Sc. honours thesis of the senior author (Wasylik, 2004), results of which are the basis of this report.

Maskells Harbour Formation

Rocks assigned to the Maskells Harbour formation (MHf) occur in two areas of the Washabuck Peninsula, a larger area extending northeast from Maskells Harbour and a smaller area west of the community of Gillis Point (Fig. 2). In the northeastern area, the rocks are well exposed in cliff sections along the coast between Maskells Harbour and Burnt Point, and in smaller outcrops inland along streams and logging roads; the coastal section along the northern shore of Maskells Harbour is considered the type section for the formation. In this section, the formation consists of

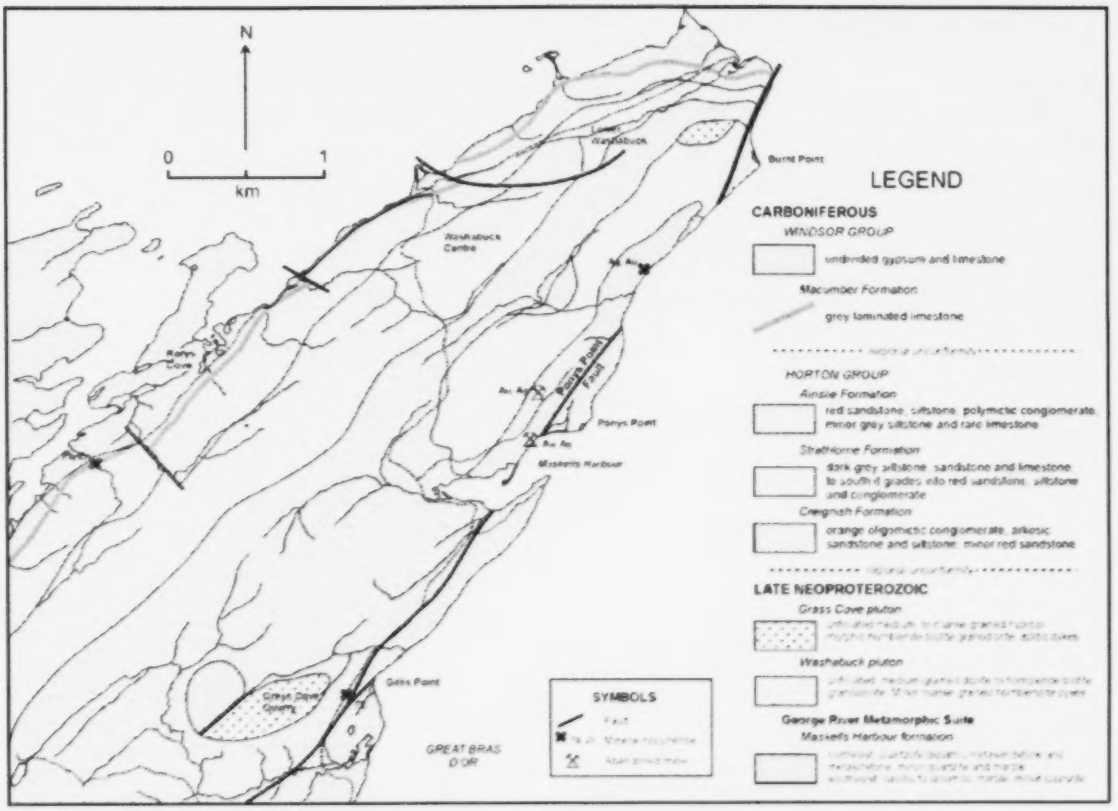

Figure 2. Geological map of the Washabuck Peninsula, simplified from Wasylik (2004).

grey interbedded quartzo-feldspathic metasandstone and metasiltstone with minor thin beds of fine-grained quartzite and fine-grained, dark grey marble. In the southern area near Gillis Point, the formation consists mainly of calcitic to dolomitic marble with minor white quartzite and quartzo-feldspathic metasandstone.

Typical samples of metasandstone and metasiltstone of the MHf contain quartz, plagioclase, microcline, biotite, muscovite, chlorite, and epidote. Foliation is defined by biotite and muscovite, with biotite more abundant (10-25%) than muscovite (less than 5%). Samples from near the contacts with the Washabuck pluton contain porphyroblasts of cordierite, heavily altered to pinite and sericite. Minor marble interbedded with the clastic rocks is fine grained and granoblastic with a weak foliation defined by minor muscovite and chlorite. Metamorphic grade in the Maskells Harbour formation is generally in the biotite zone, except near the contacts of the Washabuck pluton where contact metamorphism has produced cordierite. These contact metamorphosed units were previously considered to be correlative with gneissic units exposed at Kellys Mountain farther to the northeast (Lynch and Lafrance 1996).

Marble in the area of the formation west of Gillis Point is dominantly white, fine- to medium-grained and homogeneous, with layering evident in some places. The layered rocks consist of medium-grained calcite layers and fine-grained calcite and quartz layers. Diopside and minor tremolite occur in the quartz-rich layers, an assemblage consistent with hornblende-hornfels facies metamorphism (Blatt and Tracy, 1996). This assemblage is interpreted to be the result of contact metamorphism by the Grass Cove pluton. Zoisite has partially replaced diopside and small amounts of epidote replace tremolite, evidence of retrograde metamorphism. The quartzite varies from massive

and white to thinly layered and grey. The layered rocks are more quartzo-feldspathic and contain biotite.

Bedding in the Maskells Harbour formation dips mainly to the northwest but the distribution of poles to bedding suggests weakly developed sub-horizontal, northeast-trending folds (Fig. 3a). Foliation is sub-parallel to bedding, which results in a steep, northeast-trending intersection lineation (Fig. 3b). A northwest-trending, moderately dipping lineation (Fig. 3c), defined by quartz rods, is evident on foliation planes in some of the coarser grained metasedimentary beds.

In the coastal section northeast of Maskells Harbour, the rocks shows evidence of ductile deformation (mylonitic stretching lineations and related folds) overprinted by later faults, most notably the Ponys Point fault which separates the Maskells Harbour formation from rocks of the Windsor Group to the east. Veins of quartz and calcite are numerous, and some of the larger quartz veins were mined in the past for gold and silver. The Maskells Harbour formation hosts many of these mineral occurrences (Fig. 2) described by DeMont (1991, 1992).

Washabuck Pluton

The Washabuck pluton intruded the Maskells Harbour formation in the northeastern part of the Washabuck Peninsula (Fig. 2). The northeast-trending pluton has an exposed length of approximately 2.5 km and an average width of approximately 300 m (Fig. 2). It consists of unfoliated, medium-grained diorite, quartz diorite, tonalite, quartz monzodiorite, and hornblende-biotite granodiorite (Fig. 4). Variations among these different lithologies appear to be gradational. Also present are coarse-grained hornblende-rich rocks ('hornblendite') containing hornblende crystals up to 2 cm in length, interpreted to represent pegmatoid lenses and segregations related to the pluton. A granitic pod, with smaller pods and dykes of aplite within it, intruded the diorite in the coastal section, and a small granitic body, not observed during the present study, was reported by Jensen (1993) inland at the northern margin of the pluton. These granitic units are likely to be related to the Grass Cove pluton, described below.

Major minerals in the Washabuck pluton are plagioclase and amphibole, with variable amounts of biotite, quartz, and microcline. All samples are fine- to medium-grained, hypidiomorphic granular to inequigranular in texture with accessory opaque minerals, titanite, apatite, and zircon. Secondary minerals include sericite, saussurite, chlorite, epidote and clinozoisite. Microprobe analyses indicate that the amphibole composition is magnesio-hornblende (Wasylik, 2004). Plagioclase composition ranges from An 36-49, and biotite has a lower Al_2O_3 content than the metamorphic biotite in the Maskells Harbour formation.

Grass Cove Pluton

The Grass Cove pluton outcrops over an area of less than 1 km^2, but is well exposed in a large quarry west of Gillis Point and northwest of Grass Cove (Fig. 2). It consists mainly of pink, massive, homogeneous medium- to coarse-grained hornblende-biotite granodiorite with areas of fine-grained, grading to coarse-grained, monzogranite to syenogranite and associated muscovite-bearing aplite dykes. The granodiorite and granite units do not appear gradational, but due to limited outcrop it was not possible to map the distribution of the two rock types. Both the granodiorite and granite are dominantly unfoliated, but a weak foliation is developed in the western part of the intrusion, near and parallel to the inferred faulted contact with the Maskells Harbour formation to the west. Like the Washabuck pluton, the Grass Cove pluton contains metasedimentary xenoliths with lithologies consistent with derivation from the Maskells Harbour formation. Also present in the Grass Cove pluton are dioritic xenoliths likely derived from the Washabuck pluton.

The granitic units contain perthitic microcline, whereas the granodiorite contains less abundant orthoclase. One analysis of plagioclase in the monzogranite gave an oligoclase (An24) composition, whereas plagioclase in the granodiorite is more calcic andesine (An36). Biotite is lower in aluminum than that in the Washabuck pluton or Maskells Harbour formation (Wasylik, 2004). Minor hornblende is present in the granodiorite. Accessory minerals are magnetite, titanite and apatite in both the granite and

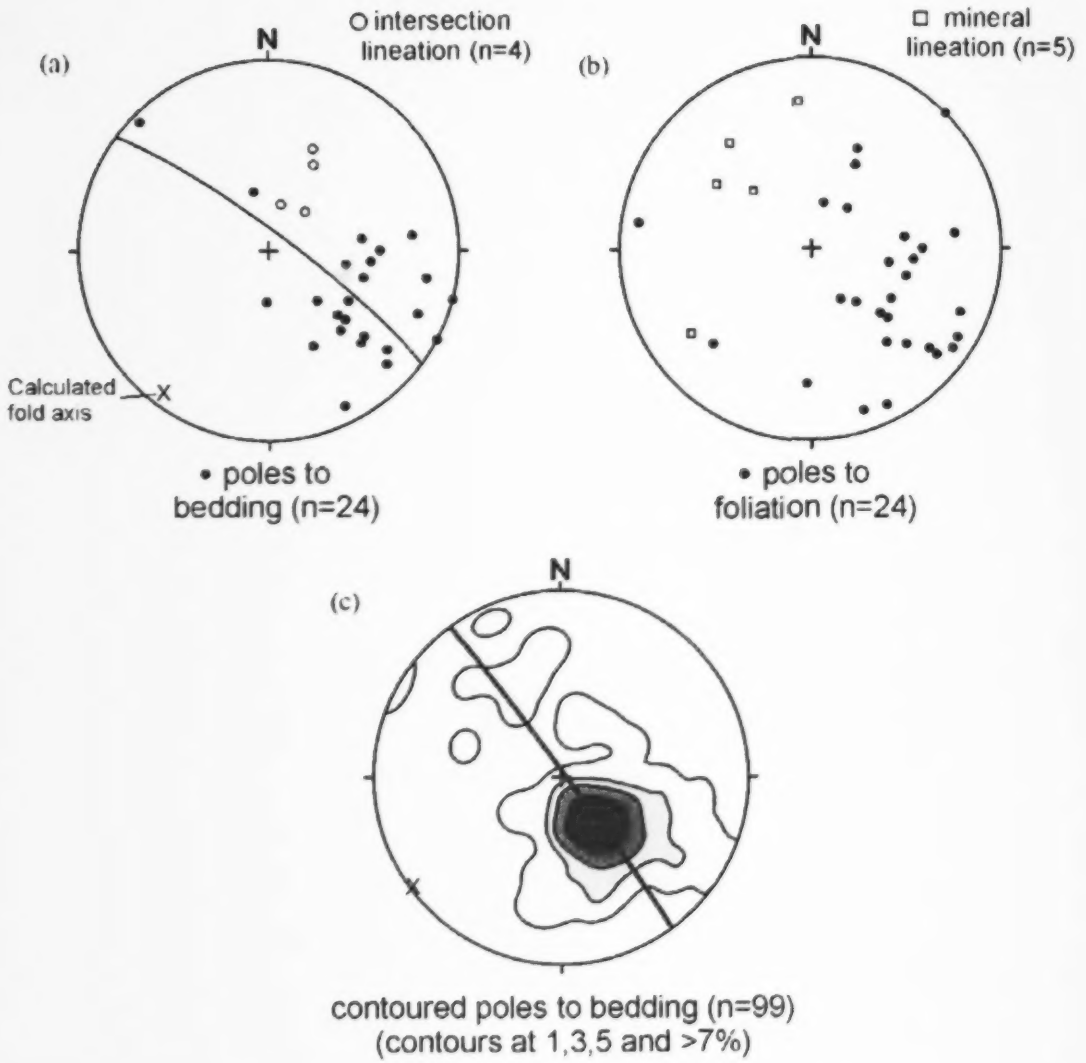

Figure 3. Structural data from the Washabuck Peninsula plotted on equal area stereonets. (a) Poles to bedding (black circles, n=24) and intersection lineations (grey circles, n=4) in the Maskells Harbour formation. (b) Poles to foliation (black circles, n= 24) and mineral lineations (grey squares, n=5) in the Maskells Harbour formation. (c) Equal area stereonets showing contoured poles to bedding (n=99) in Carboniferous rocks in the area shown in Figure 2. X is the calculated fold axis. Contours are at 1, 3, 5, and >7%.

granodiorite, and the granodiorite also contains subhedral allanite.

Pods of aplite, pegmatite and medium- to coarse-grained granite in both the Maskells Harbour formation and the Washabuck pluton are likely to be related to the granitic unit of the Grass Cove pluton.

Minor Mafic Intrusive Units

Mafic dykes and sills occur in both the metamorphic and plutonic units and are of two types: fine-grained greenish-grey diorite and dark grey porphyritic diorite. Both types range in

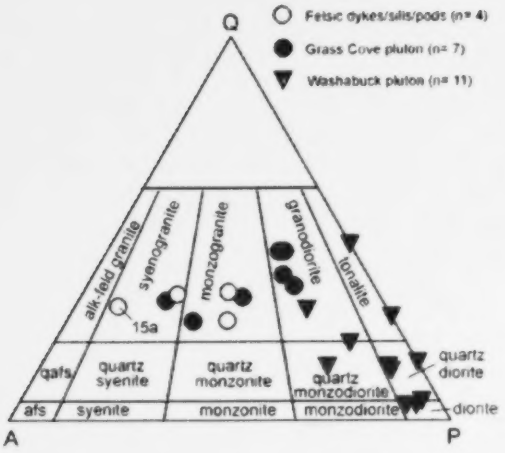

Figure 4. Modal compositions of samples from the Washabuck and Grass Cove plutons and associated felsic dykes plotted on a Q (quartz)- A (alkali feldspar) - P (plagioclase) ternary diagram with fields after Streckeisen (1976).

thickness from approximately 15 cm to 3 m, and in some places the porphyritic dykes were observed to cut the fine-grained dykes. The porphyritic dykes contain very fine-grained quartz, plagioclase, hornblende and epidote in the groundmass, with phenocrysts of plagioclase and some larger clusters of hornblende. Plagioclase is heavily altered to sericite. The fine-grained dykes consist mainly of plagioclase, hornblende, clinopyroxene and biotite.

Horton Group

Sedimentary rocks assigned to the Carboniferous Horton Group overlie the metamorphic and plutonic units (Fig. 2). Although contacts are not exposed, the shallow dips of bedding suggest that the contacts are unconformities. The Horton Group is divided into the Creignish, Strathlorne, and Ainslie formations based on lithological comparisons to the Horton Group elsewhere in the region (e.g. Lynch and Lafrance, 1996). In the Washabuck Peninsula, the Creignish Formation consists of orange oligomictic conglomerate, arkosic sandstone and siltstone with minor red sandstone and siltstone. Clasts in the conglomerate are dominantly granitic with minor quartzite and resemble units in the underlying Washabuck and Grass Cove plutons, and Maskells Harbour formation. The overlying Strathlorne Formation is characterized by dark grey siltstone, sandstone, and thin impure limestone. Although red sandstone and siltstone are typically absent in the Strathlorne Formation, they increase in abundance towards the top of the unit, which is conformably overlain by red sandstone, siltstone and polymictic conglomerate and minor grey siltstone of the Ainslie Formation. Grey, locally algal to oolitic limestone beds occurs throughout the Ainslie Formation.

Bedding orientations in the Carboniferous units indicate a southwest-plunging anticline cored by the Maskells Harbour formation, Washabuck pluton and Grass Cove pluton (Fig. 3c). Minor local faulting occurs in the Carboniferous units along the northwest coast of the peninsula.

Windsor Group

The Windsor Group in the Washabuck Peninsula is divided into the basal Macumber Formation, which consists of grey laminated limestone, and an upper undivided gypsum and limestone unit with minor siltstone (e.g. Hein *et al.*, 1988). Along the northwestern margin of the peninsula, an outcrop shows a disconformable contact between the Ainslie Formation of the Horton Group and the Macumber Formation of the Windsor Group. In the southeastern part of the peninsula, the Windsor Group is in faulted contact, along the Ponys Point fault, with pre-Carboniferous rocks.

Geochemistry

Major and trace element analyses were obtained for representative samples from the Washabuck and Grass Cove plutons, as well as from granitic and mafic dykes and sills in these units. The data and analytical methods were presented by Wasylik (2004), and only a summary of the results is presented here.

Eleven samples analyzed from the Washabuck pluton range in SiO_2 content from 50.15% to 62.31% (Fig. 5). Dioritic samples have the lowest SiO_2 contents, and a granodiorite sample has the highest SiO_2 content. TiO_2, $Fe_2O_3^t$, MgO, CaO and P_2O_5 all show strong negative correlation with SiO_2, whereas Na_2O and K_2O show a scattered positive correlation (Fig. 5). Al_2O_3 contents vary

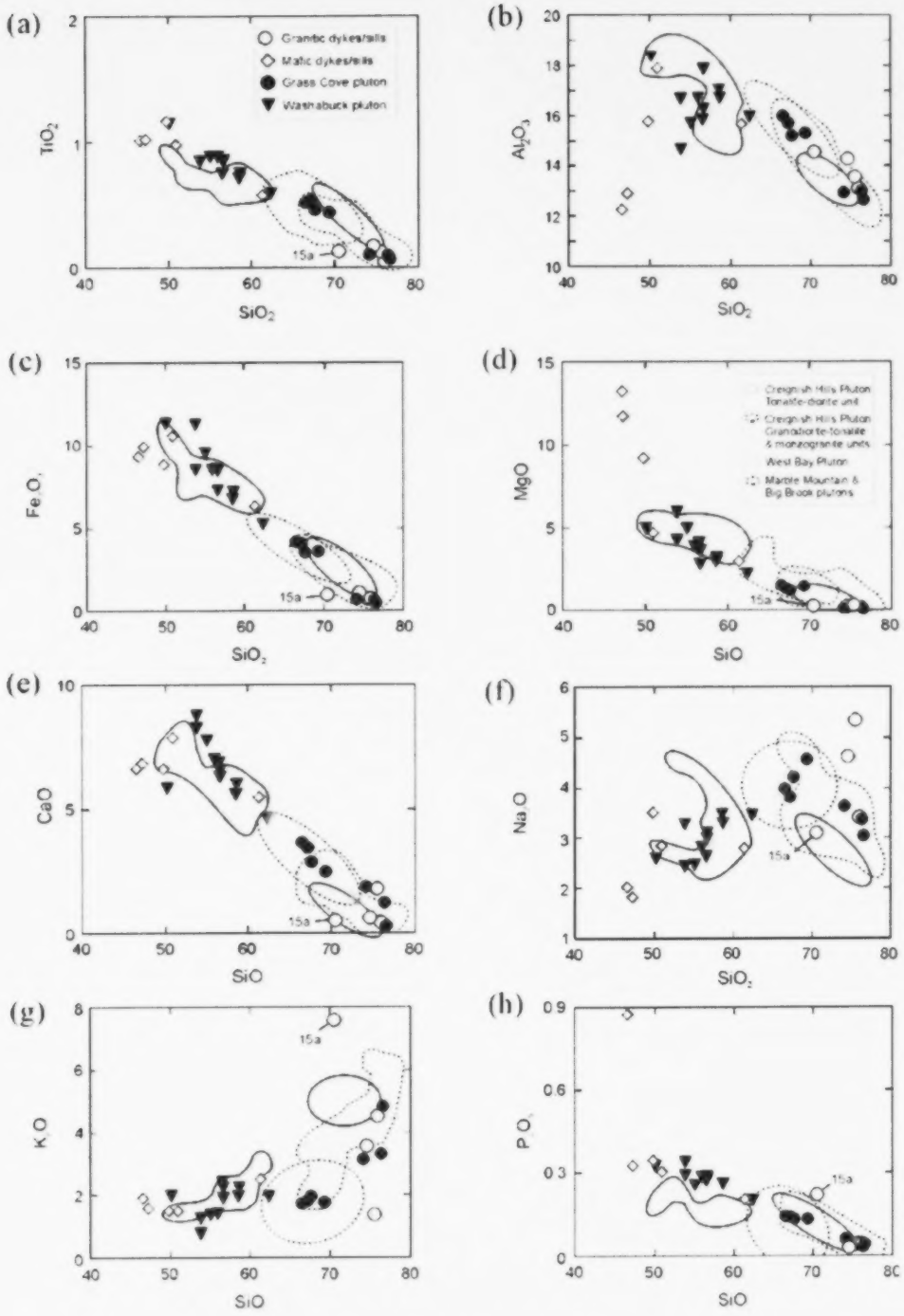

Figure 5. Plots of selected major element oxides against SiO_2 to illustrate chemical variation in the Washabuck and Grass Cove plutons and associated mafic and felsic dykes. Fields for plutons in the Creignish Hills and North Mountain areas (Fig. 1) are shown for comparison.

from 14.65% to 18.39 % and show little correlation with SiO_2 (Fig. 5b).

The seven samples analyzed from the Grass Cove pluton range in SiO_2 content from 66.43% to 76.51% (Fig. 5). The four granodiorite samples have the lowest SiO_2 contents (66-70%), whereas the monzogranite and syenogranite samples have the highest SiO_2 content, (ca. 75%). In the felsic samples as a whole, Al_2O_3, TiO_2, $Fe_2O_3^t$, MgO, CaO, Na_2O, and P_2O_5 all show strong negative correlation with SiO_2, and K_2O shows strong positive correlation (Fig. 5). The most felsic granodiorite sample in the Washabuck pluton is chemically similar to the lowest SiO_2 granodiorite sample from the Grass Cove pluton, suggesting that the two plutons could be co-magmatic and related by crystal fractionation processes, although the gaps in SiO_2 contents suggests that not all components of the plutonic suite are exposed. Three granitic dykes are generally similar in composition to the monzogranite/syenogranite samples from the Grass Cove Pluton, supporting the interpretation based on petrographic features that they are related to that unit. However, a fourth dyke of syenogranite composition (15a on Fig. 4) has lower SiO_2 , similar to that in the granodiorite samples, but with much lower TiO_2, $Fe_2O_3^t$, MgO, CaO and Na_2O, and much higher K_2O and P_2O_5 (Fig. 5), and is unlikely to be directly related to the other granitic units.

Three of the mafic dyke/sill samples are basaltic (ca. 50% or less SiO_2) but two samples, both from porphyritic dykes in the Maskells Harbour formation, have higher SiO_2 and are chemically very similar to the sample suite from the Washabuck pluton, to which they are likely related. The other dykes occur in both the Maskells Harbour formation and the plutonic units, show chemical differences from the dioritic Washabuck pluton samples, and are probably younger than and unrelated to the pluton.

Trace elements generally display more variation than the major element oxides. Typical examples are illustrated in Figure 6. Wide variation in Ba and Rb in the granitic samples suggest the influence of K-feldspar fractionation in the later stages of magma evolution. Metal levels are generally low, but some of the Washabuck pluton samples show elevated levels of Pb, Zn, and/or Cu (Fig. 6f, g, h).

On the AFM diagram (Fig. 7), the samples overall display a calc-alkaline trend for both plutons, with a prominent gap between the granodiorite and monzogranite/syenogranite samples in the Grass Cove pluton. On this diagram, the Washabuck pluton and granodiorite unit of the Grass Cove pluton appear related whereas the granitic dykes and sills appear to be related to the granitic parts of the Grass Cove pluton.

Samples with more than 60% SiO_2 plot in the volcanic-arc granite field on the Rb/Y+Nb discrimination diagram (Fig. 8a). Samples with less than 55% SiO_2 from the Washabuck pluton and mafic dykes and sills plot in the calc-alkalic basalt field of the Ti-Zr-Y discrimination diagram (Fig. 8b).

Taken all together, the chemical characteristics indicate calc-alkalic chemical affinity for samples from the Washabuck Peninsula area, and are consistent with origin in a volcanic-arc setting. Given the range in compositions, the Washabuck and Grass Cove plutons can be considered to be an I-type granitoid suite, which typically form in a continental margin subduction zone such as the modern-day Andes (e.g. Pitcher, 1983). However, given the small areas of exposure of these units, it is likely that the full range of compositions in the original plutons is not represented by the sample set.

Regional Correlations

The Maskells Harbour formation is similar to units elsewhere in the Bras d'Or terrane that make up the George River Metamorphic Suite, especially the Blues Brook and Malagawatch formations (Campbell 1990). Like the Maskells Harbour formation, these units consist of metapelite, calcitic and dolomitic carbonate-bearing rocks, and quartzite, as well as minor metavolcanic rocks not found in the Maskells Harbour formation. Based on location along trend from the Barachois River Metamorphic Suite (Fig. 1), Raeside and Barr (1990) suggested that metamorphic rocks here assigned to the Maskells Harbour formation, as well as those across Bras d'Or Lake at Beinn Breagh, are low-grade portions of that suite. The Barachois River Metamorphic Suite, however, lacks marble and calc-silicate rocks, so that correlation may not be correct.

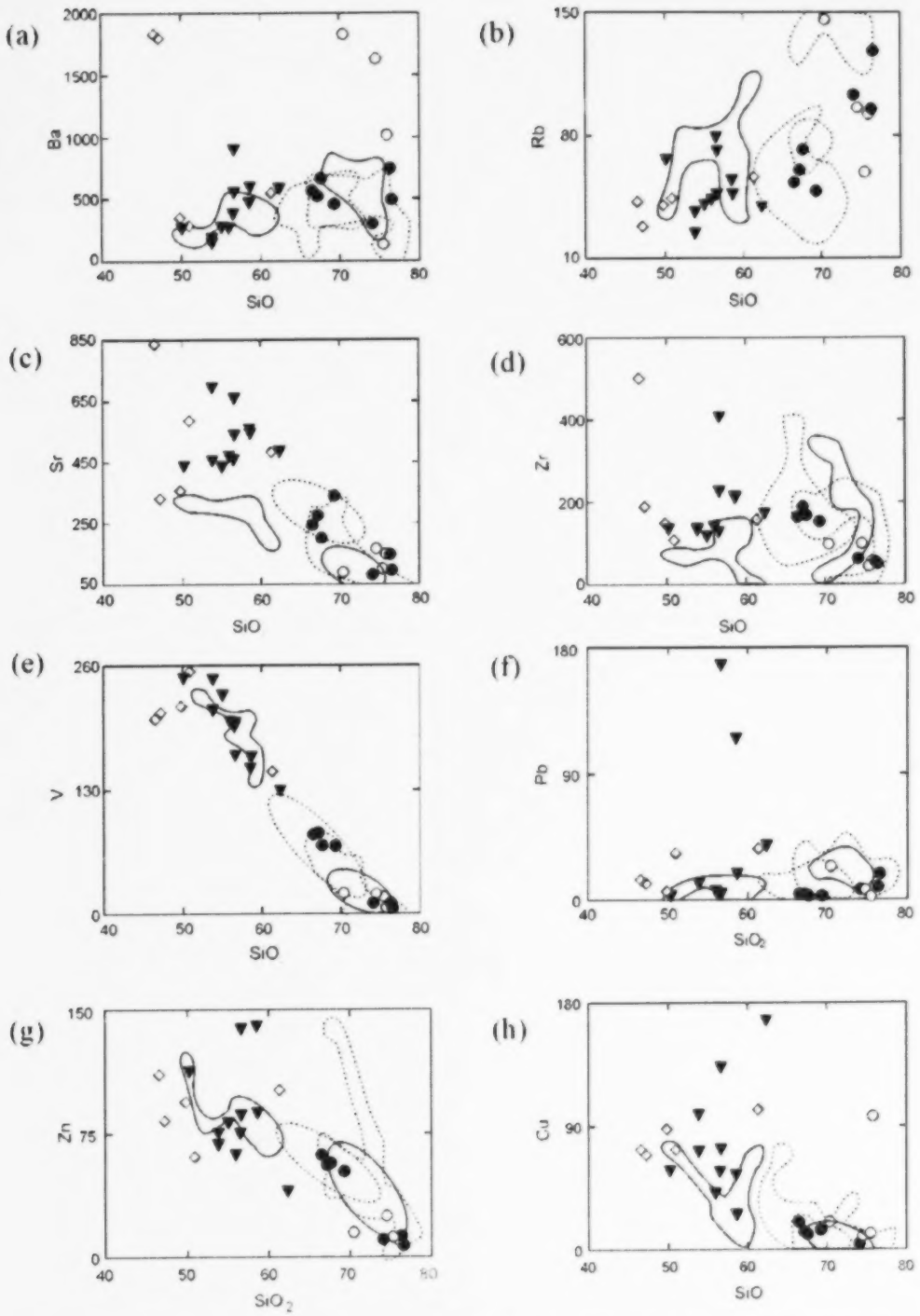

Figure 6. Plots of selected trace elements against SiO_2 to illustrate chemical variation in the Washabuck and Grass Cove plutons and associated mafic and felsic dykes. Fields for plutons in the Creignish Hills and North Mountain areas (Fig. 1) are shown for comparison.

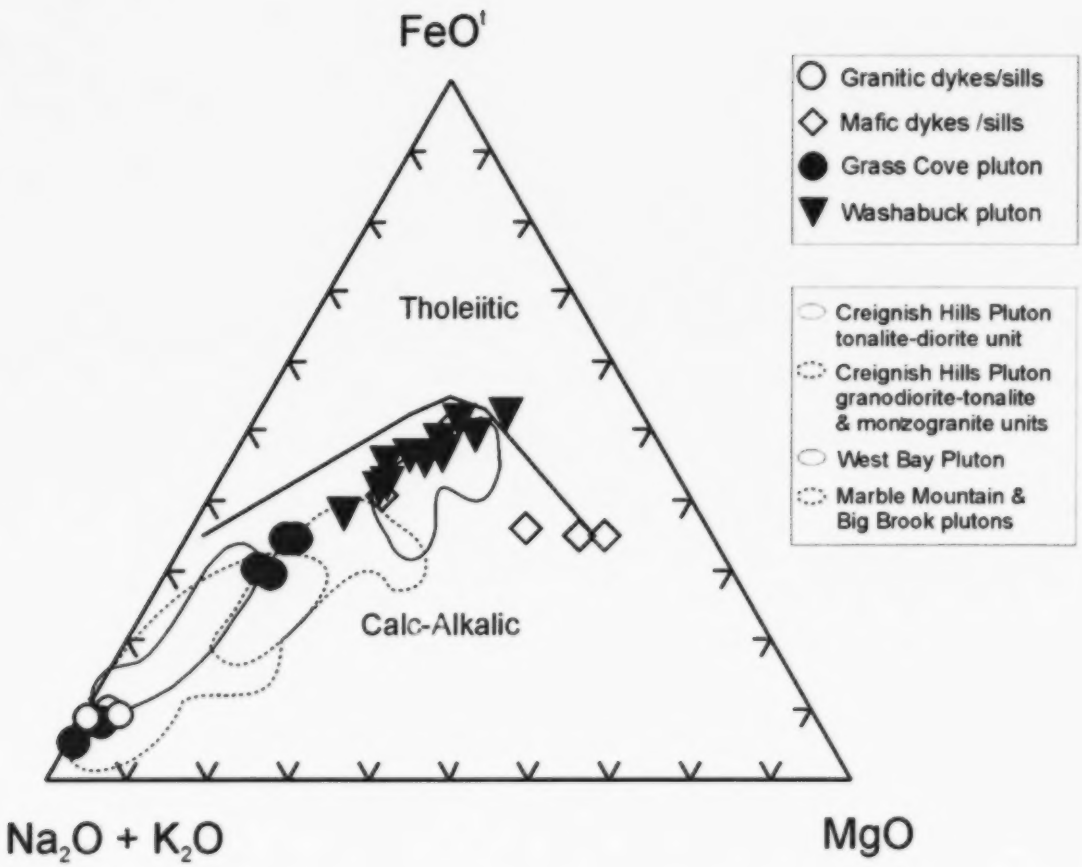

Figure 7. Samples from the Washabuck and Grass Cove plutons and associated mafic and felsic dykes plotted on an AFM diagram with tholeiitic-calc-alkalic dividing line from Irvine and Baragar (1973). Fields for plutons in the Creignish Hills and North Mountain areas (Fig. 1) are shown for comparison.

Late Neoproterozoic and Late Cambrian plutonic rocks are characteristic of the Bras d'Or Terrane (Raeside and Barr, 1990; Fig. 1). The Creignish Hills and related satellite plutons include tonalite-diorite, granodiorite-monzogranite, and monzogranite units (White *et al.*, 1990, 2003), and the Marble Mountain, Big Brook, and West Bay plutons of the North Mountain area also include similar rock types (Justino and Barr, 1994). These units show chemical trends very similar to those in the Washabuck and Grass Cove plutons, although the Washabuck Pluton tends to have higher CaO, P_2O_5, and Sr abundances (Figs. 5, 6). All of these plutons show similar calc-alkalic trends on the AFM diagram (Fig. 7), and likely formed in a continental margin subduction zone setting (Raeside and Barr, 1990; Grecco and Barr, 1999).

Most of the plutonic rocks in the Creignish Hills and North Mountain areas have yielded precise U-Pb ages of ca. 553 Ma (White *et al.*, 2003). Hence it is likely that the Washabuck and Grass Cove plutons are of similar late Neoproterozoic age. The protolith age of the George River Metamorphic Suite is less well constrained, but likely to be ca. 650 Ma (Keppie *et al.*, 1998; Barr *et al.*, 2003). The mainly unfoliated character of the plutonic rocks indicates that they were emplaced after regional metamorphism and deformation of their host rocks.

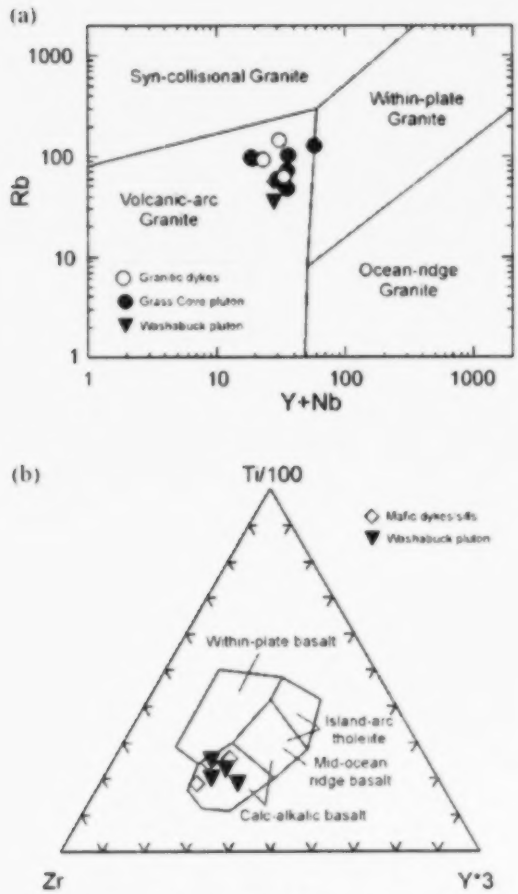

Figure 8. Tectonic setting discrimination diagrams for (a) granitoid and (b) mafic rocks after Pearce *et al.* (1986) and Pearce and Cann (1973), respectively. Samples from the study area with more than 60% SiO_2 are plotted on (a) and those with less than 55% SiO_2 are plotted on (b).

Conclusions

The Washabuck Peninsula is underlain by metasedimentary rocks of the Maskells Harbour formation, part of the George River Metamorphic Suite of the Bras d'Or terrane. The formation is intruded by dioritic to granodioritic rocks of the Washabuck Pluton, and granodioritic and monzogranitic to syenogranite rocks of the Grass Cove Pluton. Similarity to dated plutons in other areas of the Bras d'Or terrane suggests an age of ca. 553 Ma for both plutons. Their petrological features indicate that they are part of an I-type granitoid suite emplaced as a result of subduction at a continental margin. Carboniferous sedimentary rocks of the Horton and Windsor groups surround the exposed Precambrian units.

Acknowledgments

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References

Barr, S. M. and Raeside, R. P. 1989: Tectonostratigraphic divisions in Cape Breton Island, Nova Scotia: implications for the configuration of terranes in the northern Appalachian Orogen; Geology, v. 17, p. 822-825.

Barr, S. M., Davis, D. W., Kamo, S. and White, C. E. 2003: Significance of U-Pb detrital zircon ages in quartzite from peri-Gondwanan terranes, New Brunswick and Nova Scotia, Canada; Precambrian Research, v. 126, p. 123-145.

Blatt, H. and Tracy, R. J. 1996: Petrology: Igneous, Sedimentary and Metamorphic, 2nd ed.: New York, W. H. Freeman and Company, p. 378-379.

Campbell, J. E. M. 1990: The Geology of the northeastern Creignish Hills, Cape Breton Island, Nova Scotia; M.Sc. thesis, Acadia University, Wolfville, Nova Scotia

DeMont, G. J. 1991: Selected mineral occurrences of Cape Breton Island; Nova Scotia Department of Mines and Energy, Open File Report 91-002.

DeMont, G. J. 1992: Selected metallic mineral occurrences of Cape Breton Island; Nova Scotia Department of Mines and Energy, Open File Report 92-010, p. 101-107.

Goudge, M. F. 1934: Limestones of Canada: Their occurrence and characteristics, part II, Maritime Provinces; Canada Department of Mines, No. 742, p. 107, 114.

Grecco, L. E. and Barr, S. M. 1999: Late Neoproterozoic granitoid and metavolcanic rocks of the Indian Brook area, southeastern Cape Breton Highlands, Nova Scotia; Atlantic Geology, v. 35, p. 43-58.

Hein, F. J., Graves, M. C. and Ruffman, A., 1988: The geology of the Jubilee zinc-lead deposit, Victoria County, Cape Breton Island, Nova Scotia; Geological Survey of Canada, Open File 1891.

Irvine, T. N. and Baragar, W. R. A. 1971: A guide to the chemical classification of the common volcanic rocks; Canadian Journal of Earth Sciences, v. 8, p. 523-548.

Jensen, L. 1993: Burnt Point geological and lithogeochemical and biogeochemical Survey, Victoria County Nova Scotia; Nova Scotia Department of Mines and Energy Assessment Report 93-052.

Jensen, L. 1995a: Grass Cove Claims, Victoria County, Nova Scotia; Nova Scotia Department of Mines and Energy Assessment Report 95-040.

Jensen, L. 1995b: Maskells Harbour Property, Victoria County, Nova Scotia; Nova Scotia Department of Mines and Energy Assessment Report 95-043.

Justino, M. F. and Barr, S. M. 1994: Petrology, petrogenesis and tectonic setting of plutonic rocks in the North Mountain area, west-central Cape Breton Island, Nova Scotia; Atlantic Geology, v. 30, p. 47-64.

Keppie, J. D. 1979: Geological map of the Province of Nova Scotia; Nova Scotia Department of Mines and Energy, scale 1: 500 000.

Keppie, J. D. (compiler) 2000: Geological Map of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Map ME 2000-1, scale 1: 500 000.

Keppie, J. D., Davis, D. W. and Krogh, T. E. 1998: U-Pb geochronological constraints on Precambrian stratified units in the Avalon composite terrane of Nova Scotia, Canada: tectonic implications: Canadian Journal of Earth Sciences, v. 35, p. 222-236.

Lynch, G. and Lafrance, B. 1996: Bedrock Geology, Baddeck (11K/02); Geological Survey of Canada, Open File 2488, scale 1: 50 000.

Milligan, G. C. 1970: Geology of the George River Series, Cape Breton; Nova Scotia Department of Mines and Energy, Memoir 7.

Pearce, J. A. and Cann, J. R. 1973: Tectonic Setting of basic rocks determined using trace element data; Earth and Planetary Science Letters, v. 19, p. 290-300.

Pearce, J. A., Harris, N. B. W. and Tindle, A. G. 1984: Trace element discrimination diagrams for the tectonic interpretation of granitic rocks; Journal of Petrology, v. 25, p. 956-983.

Pitcher, W. S. 1983: Granite type and tectonic environment, *in* ed. K. Hsü, Mountain building processes: London, Academic Press, p. 19-40.

Raeside, R. P. and Barr, S. M. 1990: Geology and tectonic development of the Bras d'Or suspect terrane, Cape Breton Island, Nova Scotia; Canadian Journal of Earth Sciences, v. 27, p. 1371-1381.

Streckeisen, A. 1976: To each plutonic rock its proper name; Earth Sciences Reviews, v. 12, p. 1-33.

Wasylik, D. 2004: Geology of the Washabuck Peninsula, central Cape Breton Island, Nova Scotia. BSc honours thesis, Acadia University.

White, C. E., Barr, S. M. and Campbell, M. R. 1990: Petrology of the Creignish Hills Pluton, Cape Breton Island, Nova Scotia; Atlantic Geology, v. 26, p. 109-123.

White, C. E., Barr, S. M. and Ketchum, J. W. F. 2003: New age controls on rock units in preCarboniferous basement blocks in southwestern Cape Breton Island and adjacent mainland Nova Scotia; Mineral Resources Branch, Report of Activities 2002; Nova Scotia Department of Natural Resources, Report 2003-1, p. 163-178.

Geology of the Area between Lockeport, Liverpool and Lake Rossignol, Shelburne and Queens Counties, Southwestern Nova Scotia

C. E. White

Introduction

The South Shore Nova Mapping Project was initiated in 2004 by the Nova Scotia Department of Natural Resources as a continuation of the Southwest Nova Project. The principal goals of the project are to produce a series of 1:50 000 scale geological maps of the area, describe and interpret the sedimentary, igneous, metamorphic and deformational history, and evaluate the economic potential. Reported here are results from 1:10 000 scale field mapping completed during the summer of 2004, including a preliminary bedrock geology map of the area between Lockeport, Liverpool and Lake Rossignol in Shelburne and Queens counties (Figs. 1, 2) and includes parts of NTS map areas 20P/10, 14, and 15 and 21A/02 and 03.

Details of the mapping program and methodology are similar to those in the Southwest Nova Project (Fig. 1), as summarized by White *et al.* (1999). Preliminary results since 1998 (covering all or parts of NTS map areas 21A/02 and 12, 21B/01 and 08, 21O/09 and 16, and 20P/05, 06, 11, 12, 13, and 14) were presented by White *et al.* (1999, 2001, 2003), Horne *et al.* (2000), White (2003), White and King (2002), and White and Barr (2004).

Map Units

Introduction

The earliest geological work on the meta-sedimentary rocks in the 2004 map area was undertaken by Bailey (1896) and Faribault (1914, 1915, 1918, 1920) and largely focused on structural and economic geology. Taylor (1967) subdivided the rocks in the present area into the Ordovician and earlier Goldenville and Halifax formations and noted that these units were intruded by the Devonian granodioritic Port Joli Pluton (later termed Port Mouton Pluton by Hope and Woodend, 1986). Hope and Woodend (1986), Hope (1987), and Hope *et al.* (1988) followed the subdivisions established by O'Brien (1986, 1988) and Waldron (1992) in the Meguma Group farther to the northeast, and subdivided the Goldenville Formation into the New Harbour and West Dublin members and the Halifax Formation into the Moshers Island and Cunard members. Although similar, the stratigraphic units established in the map areas to the southwest by White (2003) and White and Wasylik (2003) are used in this report, as they are shown to continue into the current map area. These stratigraphic units include the Late Neoproterozoic to Cambrian Goldenville Formation, consisting of the Green Harbour, Government Point, and Moshers Island members, and the overlying Cambrian to Early Ordovician Cunard member of the Halifax Formation. These units have been deformed and regionally metamorphosed, with grade ranging from biotite (greenschist facies) in the northeastern half of the map area to locally sillimanite-bearing migmatite (amphibolite facies) in the southwestern half. The metamorphic units are intruded by the Devonian Port Mouton Pluton (Hope and Wooden, 1986) and the gabbroic Late Triassic Shelburne Dyke.

Goldenville Formation

The Goldenville Formation is subdivided into two main units termed the Green Harbour and Government Point members, which are similar in distribution to the New Harbour and West Dublin members defined by Hope (1987). The Moshers Island member in the study area (Hope, 1987) and farther to the northeast in Queens and Lunenburg counties (O'Brien, 1986, 1988; Waldron, 1992) is defined as representing the base of the overlying Halifax Formation. However, based on field evidence (see below) the Moshers Island member is here interpreted to mark the top of the Goldenville Formation in the map area.

White, C. E. 2005: *in* Mineral Resources Branch, Report of Activities 2004; Nova Scotia Department of Natural Resources, Report ME 2005-1, p. 129-144.

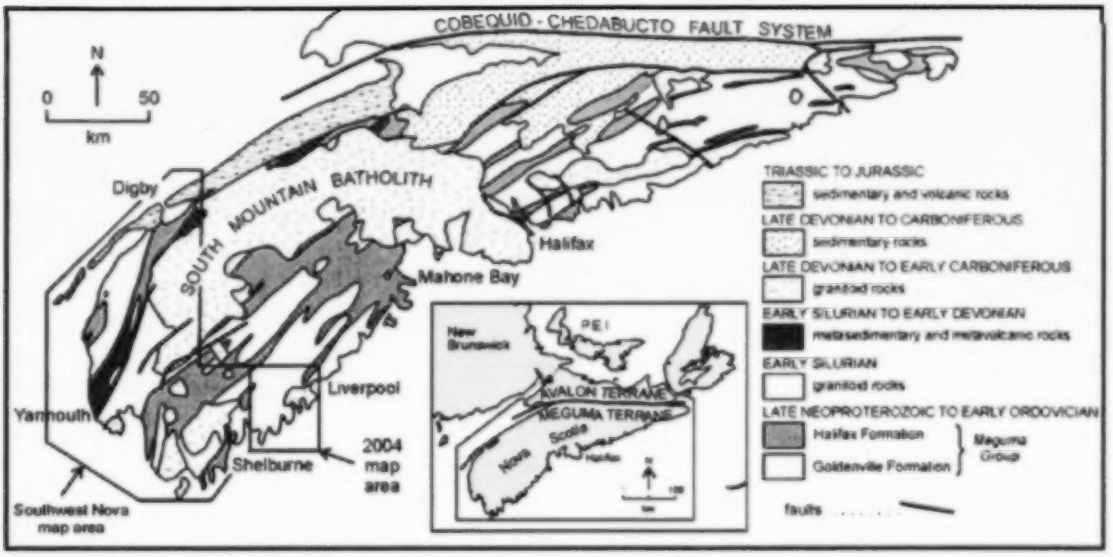


Figure 1. Simplified geological map of the Meguma Terrane, Nova Scotia, showing location of the mapped area related to the Southwest Nova Mapping Project and the 2004 map area.

Green Harbour Member

The Green Harbour member is the largest unit in the map area (Fig. 2) and consists of grey thick-bedded metasandstone that is locally interlayered with green, cleaved metasiltstone. Minor black slate interbeds are present. As metamorphic grade increases towards the pluton, the more pelitic beds are spotted first with biotite, followed by staurolite, cordierite, and andalusite. Migmatitic rocks are present near Summerville Beach. The metasandstone is light grey, thickly bedded and typically contains abundant elliptical calc-silicate lenses and beds. Original sedimentary structures are common, which aids in determining stratigraphic tops. Trace fossils are not common but large *Psammichnites* and *Phycodes*(?) grazing traces have been observed at the top of large metasandstone beds southwest of Little Port L'Hebert (Fig. 2). The Green Harbour member typically displays a uniform low aeromagnetic response throughout the area (King, 1997a, b, c, d, and unpublished data). The Green Harbour member is conformably overlain by the Government Point member near Blue Island, Western Head and Arnold, and also in Broad River (Fig. 2). The contact is marked by an increase in more pelitic interbeds and a thinning of the massive metasandstone beds and occurs over a 100 to 500 m interval. This contact is also marked by a higher positive aeromagnetic response.

Government Point Member

In areas of low metamorphic grade, the Government Point member is typically composed of grey, thinly bedded metasandstone, rhythmically laminated metasiltstone, and black slate. At higher metamorphic grade, around the western margin of the Port Mouton Pluton, the more pelitic beds in the member are composed of garnet-sillimanite schist/granofels. As in the Green Harbour member, calc-silicate nodules are very common in the metasandstone. Burrowing J-shaped trace fossils were observed in the metasandstone beds, and are typically deformed into elongate V-shaped features. A quartz-pebble conglomerate is exposed along the west side of Lockeport Harbour and forms deeply scoured channels in a 20 m-wide sedimentary slump structure that can be traced for 100 m along strike. The Government Point member is characterized by thin, alternating bands of high and low aeromagnetic signatures that reflect the high magnetite content of the interlayered pelitic beds. The Government Point member is best exposed along the shore northwest of Blue Island, in Lockeport Harbour, and in Broad River (Fig. 2).

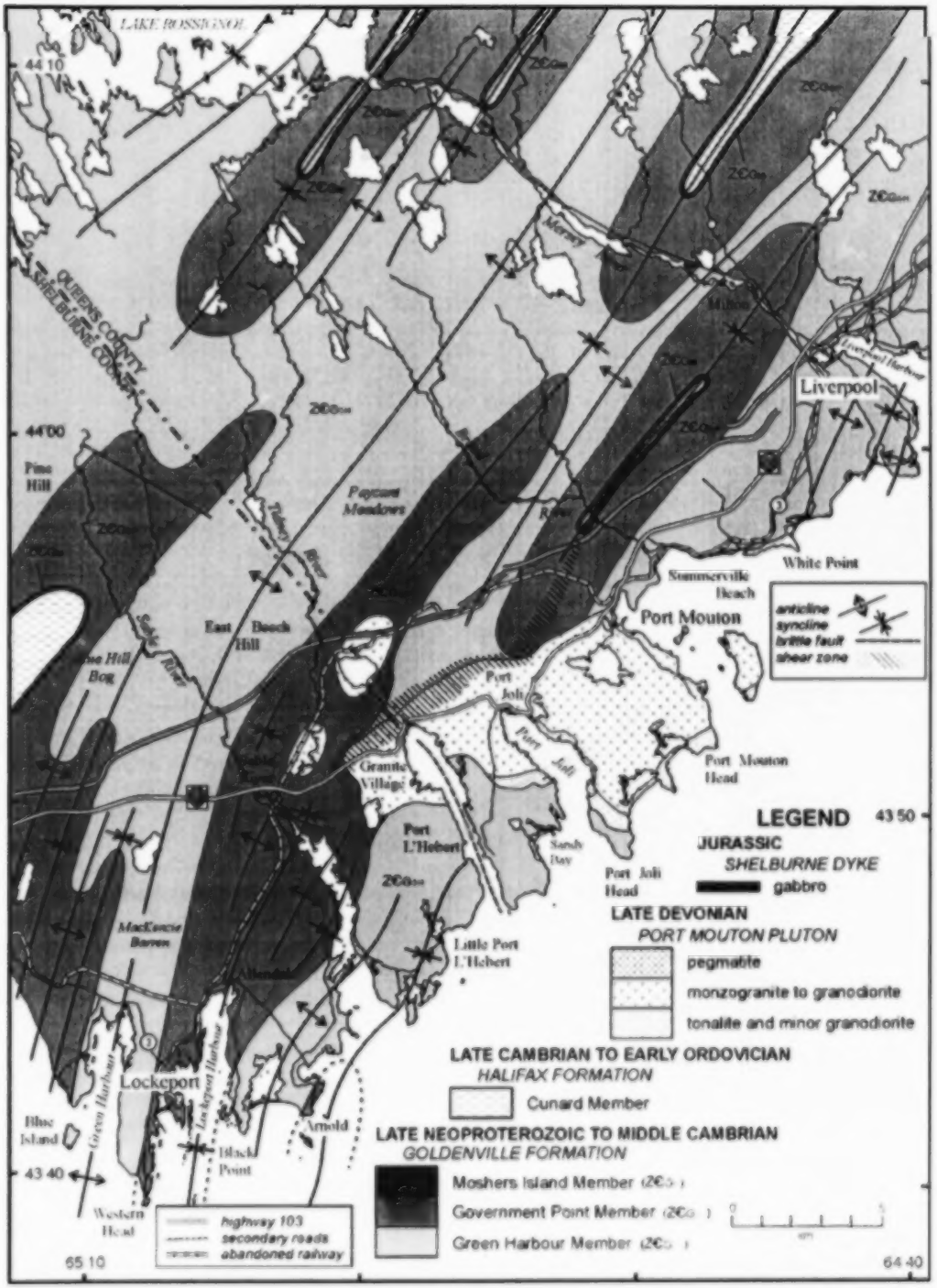
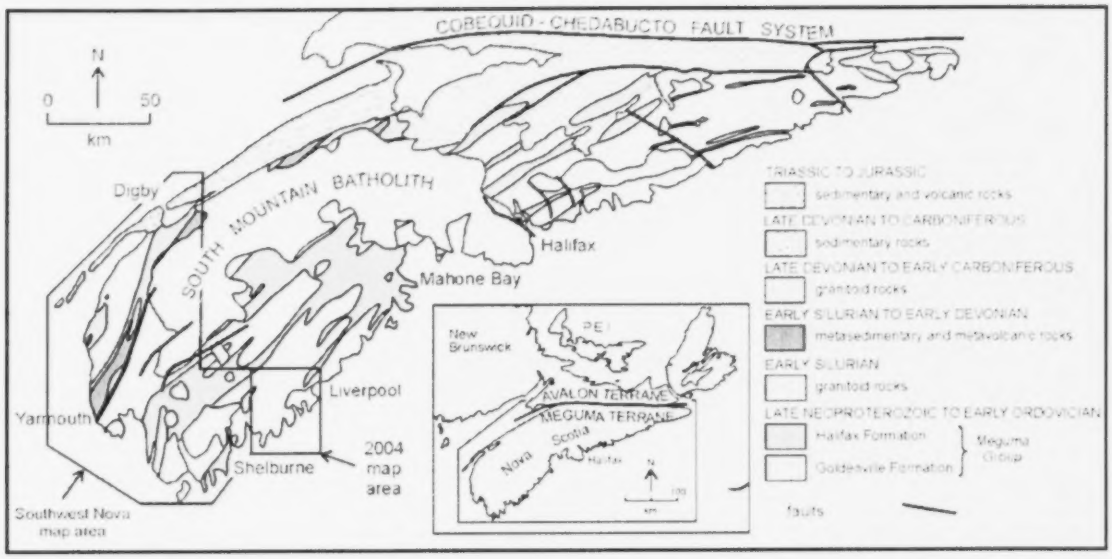


Figure 2. Simplified geological map of the area between Lockeport, Liverpool and Lake Rossignol, Shelburne and Queens counties, southwestern Nova Scotia.



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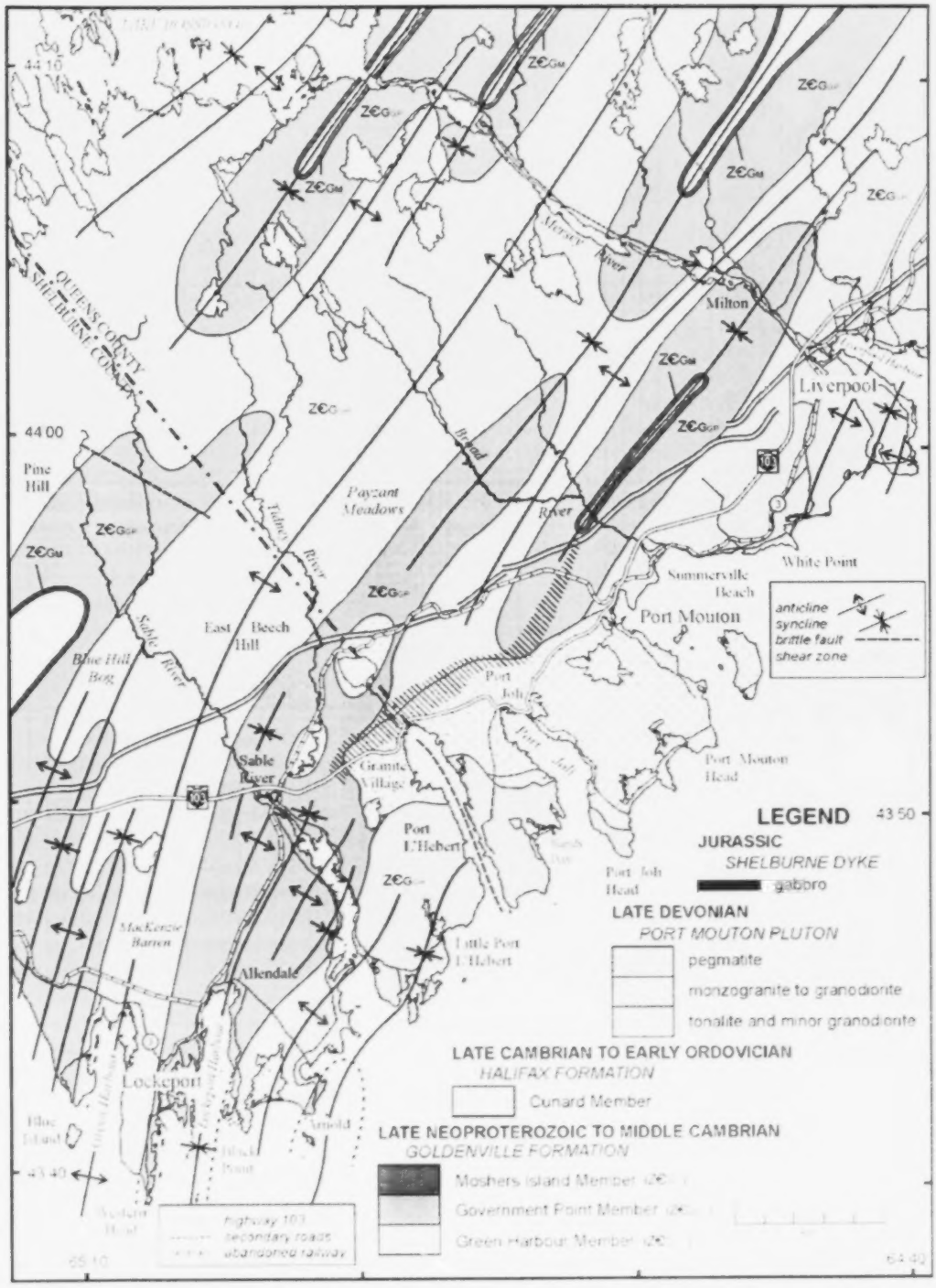


Figure 2. Simplified geological map of the area between Lockeport, Liverpool and Lake Rossignol, Shelburne and Queens counties, southwestern Nova Scotia.

Moshers Island Member

The Moshers Island member is a narrow (<100-300 m wide) unit of green to green-grey to grey, well laminated metasiltstone to slate interlayered with 1 to10 cm thick metasandstone beds. Toward the top of the member the metasiltstone is interlayered with rare black slate. A characteristic feature in this unit is thin (up to 10 cm wide), pink coticule beds and lenses that are more abundant toward the top of the unit. Locally these beds are so tightly folded that the limbs are non-existent and the coticule forms rods in the noses of minor folds. At higher metamorphic grades, as exposed in Broad River, the more pelitic beds are composed of andalusite ± staurolite ± cordierite schist. The contact with the underlying Government Point member appears to be gradational over several tens of metres, and marked by a decrease in the thickness of metasandstone beds. In Broad River, however, the lower part of the Moshers Island member is cut by a steep, bedding-parallel shear zone defined by tightly folded to rootless vertically-plunging quartz veins (see structure section). Along strike to the northeast similar quartz veins are present in the same stratigraphic horizon. The contact with the overlying Cunard member is abrupt and also marked by a bedding-parallel shear zone defined by tightly folded to rootless, steeply plunging coticule beds and quartz veins, also observed to the northeast. This unit is similar in its aeromagnetic signature to that of the Government Point member, although some of the green metasiltstone beds are extremely magnetic (50-100 SI units measured in the field).

The gradational relationship with rocks in the underlying Government Point member, the presence of abundant thin metasandstone beds, and the lack of abundant black slate supports the interpretation that the Moshers Island member in the present map area is more closely linked with the Goldenville Formation than the younger Halifax Formation.

Halifax Formation

Rocks typical of the Halifax Formation are exposed in the cores of five major, tightly folded synclines (Fig. 2). The Halifax Formation consists of black to rust-brown slate with thin beds and lenses of minor black metasiltstone. It locally contains abundant pyrite and pyrrhotite. With an increase in metamorphic grade toward the southeast (syncline near the mouth of Broad River), the slate becomes increasingly andalusite-rich and locally forms bands of chiastolite-bearing slate. This unit is typical of the Cunard Formation in southwestern Nova Scotia (Hope, 1987; Hope *et al.*, 1988; White *et al.*, 1999, 2001; Horne *et al.*, 2000). Like the Moshers Island member, the Cunard member in the map area is relatively narrow and its aeromagnetic signature is indistinguishable from that of the larger Government Point member.

Port Mouton Pluton

The Port Mouton Pluton (Hope and Wooden, 1986) occurs in the southeastern part of the study area (Fig. 2) and was extensively studied by Douma (1988, 1992). As a result, the main pluton was re-mapped on only a reconnaissance scale during the present study to confirm the lithological subdivisions and contact relations described by Douma (1988, 1992). In addition, a detailed structural study was conducted and integrated with unpublished data collected by Douma (1988). The two small plugs reported by Taylor (1967) west of the main pluton were not located during the study of Hope (1987), Hope and Wooden (1986), and Douma (1988) but due to extensive logging in the area and new aeromagnetic maps, these two bodies were confirmed to exist.

Based on cross-cutting features, Douma (1988, 1992) distinguished ten distinct units in the Port Mouton Pluton, which were involved in three distinct magmatic stages (Douma, 1992; Currie and Whalen, 1994; Clarke *et al.*, 2000). Foliated, biotite tonalite and granodiorite with minor synplutonic lamprophyric dykes dominated the early granitoid stage and occur as a continuous body along the southern contact of the pluton and as discontinuous bodies along the northeastern margin (Fig. 2). At the southern contact the igneous rocks locally contain numerous metasandstone screens whereas the contact in the north is associated with migmatitic country rocks (Summerville Beach area). Tonalite and granodiorite also occur as large blocks in units formed in the middle granitoid stage. The middle granitoid stage is dominated by biotite-muscovite monzogranite to granodiorite and

occupies most of the remainder of the pluton. The northern contact with the country rocks is a large northeast-trending shear zone (see structure section). Late stage intrusions in the pluton range from biotite-muscovite tonalite to granite and occur in sheet-like pegmatitic and aplitic bodies cutting all earlier units, including the country rocks (Fig. 2).

Locally the tonalite in stage 1 and granodiorite in stage 2 display banding defined by alternating biotite-rich and biotite-poor layers and biotite schlieren. These features are interpreted to be related to magma flow (Douma, 1992; Currie and Whalen, 1994). The Port Mouton Pluton locally exhibits a very strong steep, northeast-trending tectonic foliation resulting from parallel alignment of biotite, and a lineation defined by elongate feldspar, quartz, and/or lens-shaped biotite aggregates (see structure section).

Attempts to date the Port Mouton Pluton using the conventional $^{40}Ar/^{39}Ar$ method on muscovite, biotite, and hornblende produced ages ranging from ca. 300 to 350 Ma that were attributed to either slow cooling (Keppie and Dallmeyer, 1995), thermal resetting (Reynolds *et al.*, 1987; Douma, 1988), or to have no chronological significance (Fallon *et al.*, 2001). Currie *et al.* (1998) reported magmatic monazite ages ranging from 368 ± 1 Ma (granodiorite) to 378 ± 3 Ma (tonalite) for the pluton. Clarke *et al.* (2000) established a U-Pb monazite age of 373 ± 1 Ma for the early and middle stages of the pluton. Fallon *et al.* (2001) reported $^{40}Ar/^{39}Ar$ laserprobe ages from the cores of muscovite at 373 ± 1 Ma, which suggest that the Port Mouton Pluton cooled rapidly following intrusion, whereas rims of some muscovite grains record ages as young as 315-325 Ma. These younger ages were interpreted to be either the result of reheating during the Alleghanian Orogeny or slow argon diffusion out of muscovite grain cores to rims that ceased at this time (Fallon *et al.*, 2001). Whole-rock and related isotope geochemistry implies a continental margin arc environment for the synplutonic lamprophyric dykes and by inference the remainder of the pluton (Tate and Clarke, 1995). However, Clarke *et al.* (2000) and Fallon *et al.* (2001) cited the mantle plume theory idea of Murphy *et al.* (1999) to account for the arc-like chemical signature in the Port Mouton Pluton and other plutons in the area.

Shelburne Dyke

The Early Jurassic tholeiitic Shelburne Dyke, based on aeromagnetic data, scattered outcrop and numerous float occurrences, extends across the middle part of the map area (Fig. 2). From the aeromagnetic data it is clear that the gabbroic dyke does not form one continuous sheet but appears to be offset by minor faults. In the northeastern part a small segment of the dyke appears to display an *en echelon* character. Although contacts with the country rocks are not exposed the dyke is finer grained towards the inferred margins compared to the centre.

Deformation and Metamorphism

Detailed $^{40}Ar/^{39}Ar$ studies on single grain muscovite and whole-rock samples from the Meguma Group indicate that regional greenschist facies metamorphism occurred from ca. 388-406 Ma and coincided with the Acadian Orogeny (Muecke *et al.*, 1988; Hicks *et al.*, 1999; Muir, 2000). In the map area, regional scale north- to northeast-trending folds with well developed axial planar cleavage and regional metamorphism that varies from greenschist facies in the northwest to amphibolite facies around the Port Mouton Pluton in the southeast are generally attributed to the Acadian Orogeny (e.g. Keppie, 1985).

Deformation

The identification and characterization of structural features in the map area are based on overprinting criteria and metamorphic grade. In areas where outcrop is sparse, aeromagnetic data are used to delineate the spatial extent of structural features. The area is divided into five structural domains with contrasting structural geometries (Figs. 3-7); they are similar in distribution to those defined by Hope (1987).

Domain I, in the southwestern part of the map area, comprises parts of the Jordan Bay-Green Harbour-Lockeport Harbour domains of Hope (1987) and extends from Blue Island to Black Point along the coast, northward to the area around the Shelburne Dyke (Fig. 3). In the western and eastern

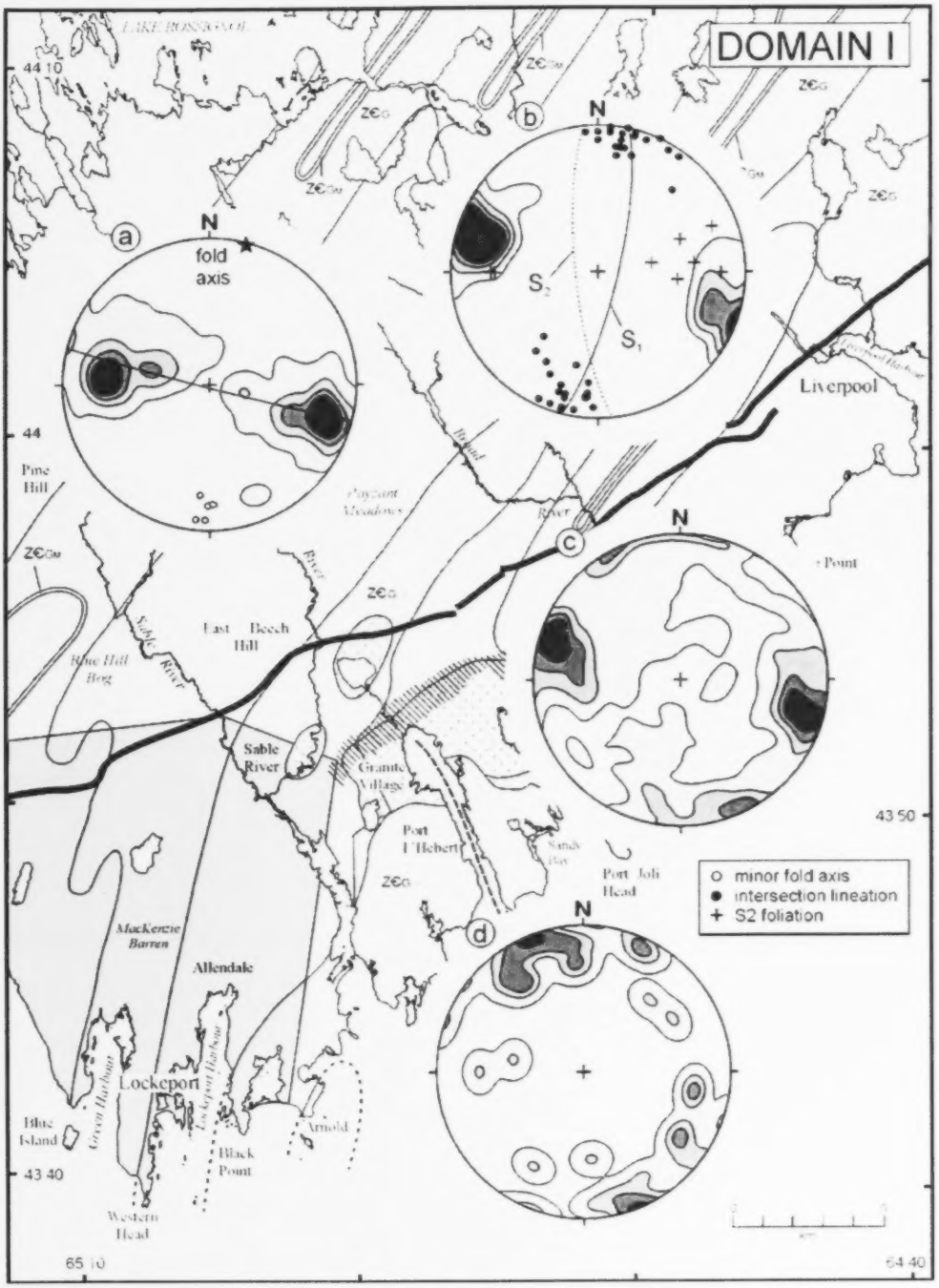
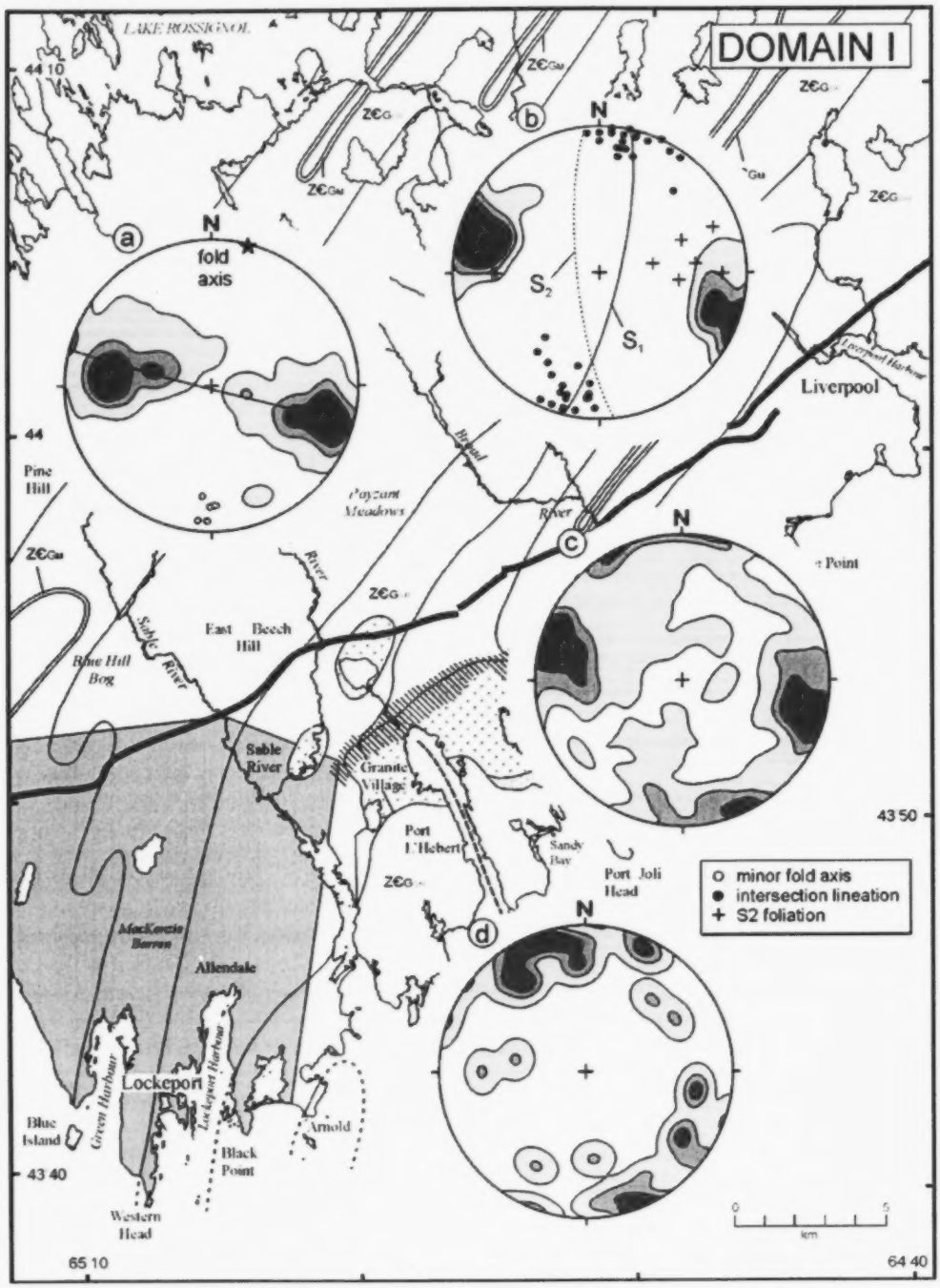


Figure 3. Equal area stereonets of structural data for Domain I (shaded grey area) in the map area. (a) Contoured poles to bedding and minor F_1 fold axes. (b) Contoured poles to foliation and bedding-cleavage intersection lineations, solid and dashed great circles show average orientation of S_1 and S_2, respectively. (c) Contoured poles to joints. (d) Contoured poles to quartz veins. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.



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part of the domain, the Government Point member is folded into several 5 to 500 m scale anticlines and synclines. The Green Harbour member is folded into a single anticline (Fig. 2). Poles to bedding (S_0) from domain I define a well developed girdle distribution with a near-horizontal, north-northeast-plunging fold axis (Fig. 3a). Poles to foliation (S_1) indicate a steep east dipping, north-northeast striking axial planar foliation (Fig. 3b). Minor F_1 folds are upright and horizontal to gently plunging southward (Fig. 3a). Intersection lineations (L_1) (bedding/foliation) are somewhat scattered but are generally subhorizontal or gently plunge to the north or south (Fig. 3b). Calc-silicate nodules typically are elongate parallel to the intersection lineation. Crenulation cleavages (S_2) are more common in the well cleaved to schistose lithologies and deform the schistosity and bedding. The crenulation cleavage strikes north with steep dips to the west (Fig. 3b) and the crenulation lineation (not plotted) is generally parallel to the minor fold axes. Although contoured poles to joints display a considerable amount of scatter, two clusters are evident (Fig. 3c). The main cluster indicates a prominent steep, north-to northeast-trending joint set that is parallel to the regional foliation and a second smaller cluster indicates a steep, northeast-to east-trending joint set (Fig. 3c). Contoured poles to quartz veins also display considerable scatter, although steep, northeast-trending quartz veins parallel to the minor joint orientations predominate (Fig. 3d).

Domain II, in the southern part of the map area, comprises the Sable River-Port L'Herbert domain of Hope (1987) and extends from Arnold to Sandy Bay along the coast, northward to southern contact with the Port Mouton Pluton (Fig. 4). Although outcrop is scarce, based on aeromagnetic data the Government Point member in the western part of the domain appears to be folded into a series of anticlines and synclines. The Green Harbour member, which makes up the remainder of the domain, is folded into a km-scale anticline and syncline (Fig. 2). Poles to bedding (S_0) define a well developed girdle distribution with a near-horizontal, southwest-plunging fold axis (Fig. 4a) and poles to foliation (S_1) indicate a steep east-dipping, northeast-striking axial planar foliation (Fig. 4b). In contrast to the regional fold axis orientation, minor F_1 folds are upright and plunge moderately southward (Fig. 4a). Intersection lineations (L_1) (bedding/foliation) are somewhat scattered but generally plung gently to moderately to the southwest (Fig. 4b). As in domain I, contoured poles to joints display a considerable amount of scatter, although the main cluster indicates a prominent steep, northeast-trending joint set that is parallel to the regional foliation in the domain (Fig. 4c). Contoured poles to quartz veins also display considerable scatter, although there is a predominance of steep, east-northeast-trending quartz veins parallel to those in domain I (Fig. 4d).

Domain III, in the southeastern part of the map area, comprises the St. Catherines River Bay domain of Hope (1987) in the area directly south of the Port Mouton Pluton in the Port Joli Head area and farther to the northeast in the White Point area (Fig. 4). In this area strike of bedding in the Green Harbour member is parallel to the contact of the pluton and the metasandstone is so injected with granite and pegmatite that most of the foliation has been obliterated by contact metamorphism (Hope, 1987). Poles to bedding (S_0) and foliation (S_1) indicate a vertical, northwest-striking average orientation for bedding and foliation (Fig. 4e, f). The distinctly different structural orientations in this domain compared to the regional structural patterns may be attributed to deflection by emplacement of the Port Mouton Pluton (e.g. Hope, 1987; Douma, 1988).

Domain IV, in the northern part of the map area, comprises the Northern-Broad River-Western Head domains of Hope (1987) and extends from the area north of the Shelburne Dyke and Port Mouton Pluton to Lake Rossignol (Fig. 5). The Goldenville and Halifax formations in this domain are folded into several regionally significant, doubly-plunging anticlines and synclines (Fig. 2) that are clearly portrayed on aeromagnetic maps (King, 1997a, b, c, d and unpublished data). Poles to bedding (S_0) define a well developed girdle distribution with a gently northeast-plunging fold axis (Fig. 5a). These data contrast with the obvious doubly-plunging attitude displayed on the aeromagnetic maps; however, minor F_1 folds are gently to moderately plunging toward the northeast and southwest (Fig. 5a). Poles to foliation (S_1) in Domain IV indicate a steep northwest-dipping, northeast- striking axial planar foliation (Fig. 5b).

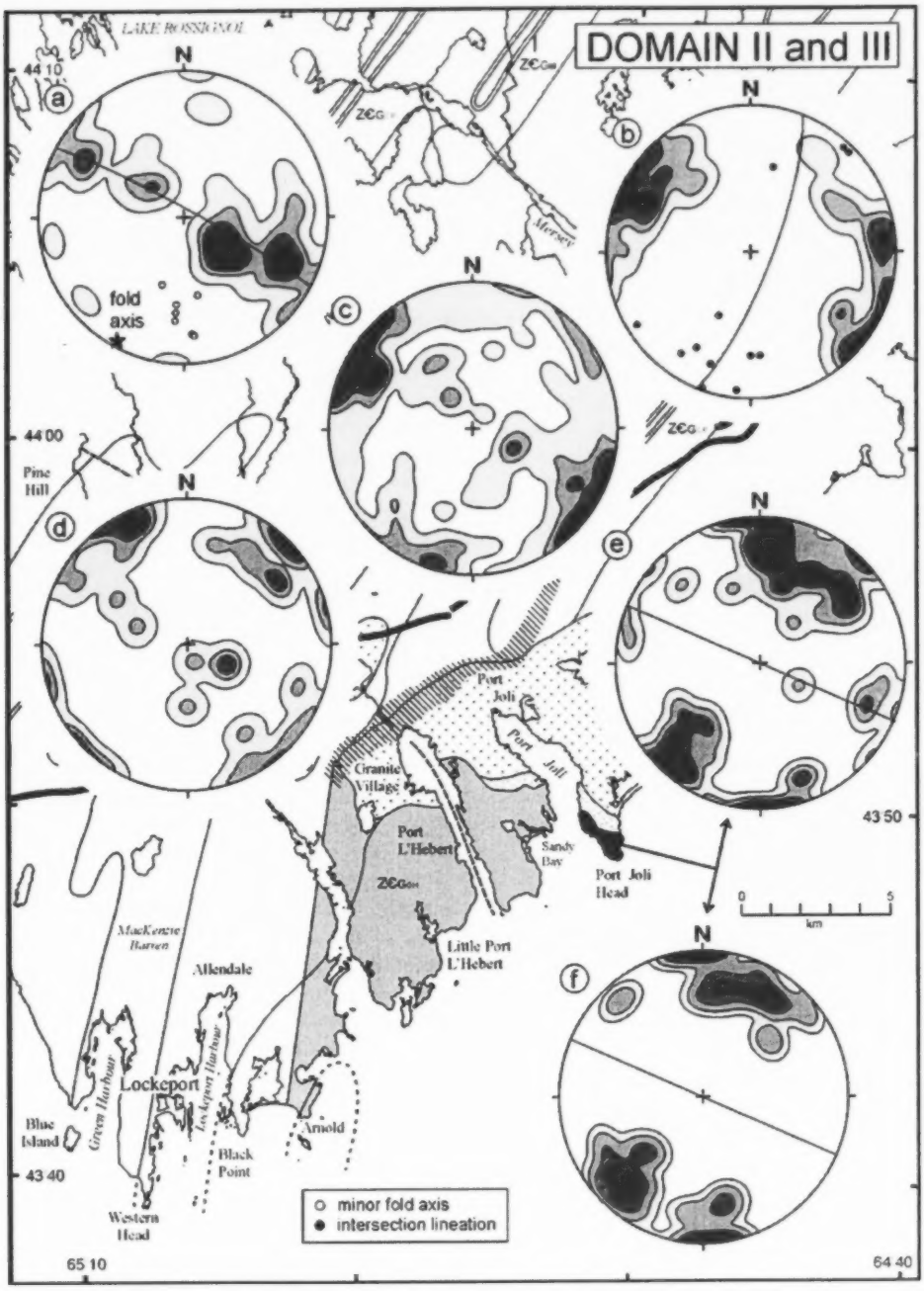


Figure 4. Equal area stereonets of structural data for Domain II and III (light and dark shaded areas, respectively) in the map area. Domain II: (a) Contoured poles to bedding and minor F_1 fold axes. (b) Contoured poles to foliation and bedding-cleavage intersection lineations, solid great circle shows average orientation of S_1. (c) Contoured poles to joints. (d) Contoured poles to quartz veins. Domain III: (e) Contoured poles to bedding, solid line shows average orientation of S_0 . (f) Contoured poles to foliation, solid line shows average orientation of S_1. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.

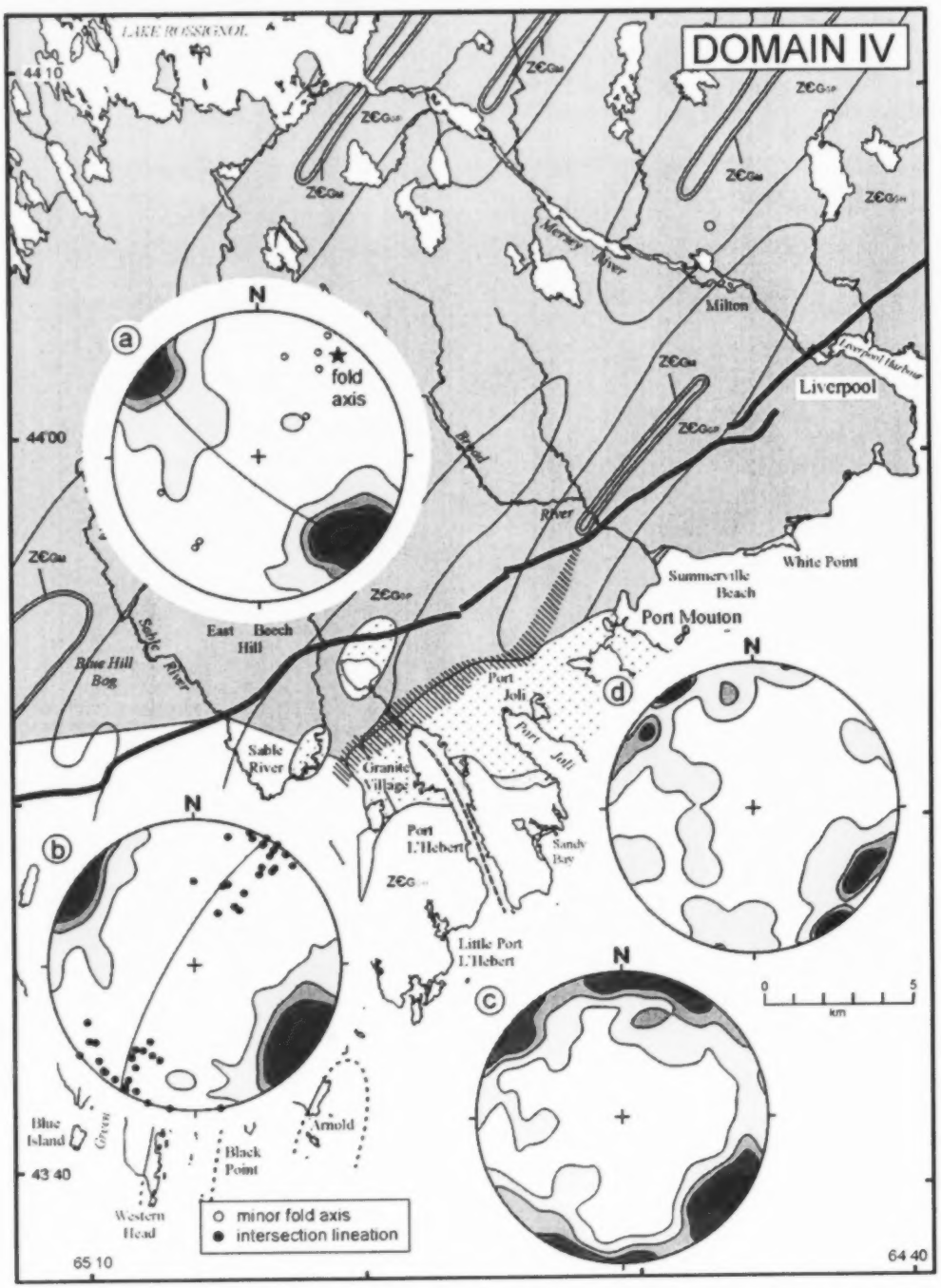
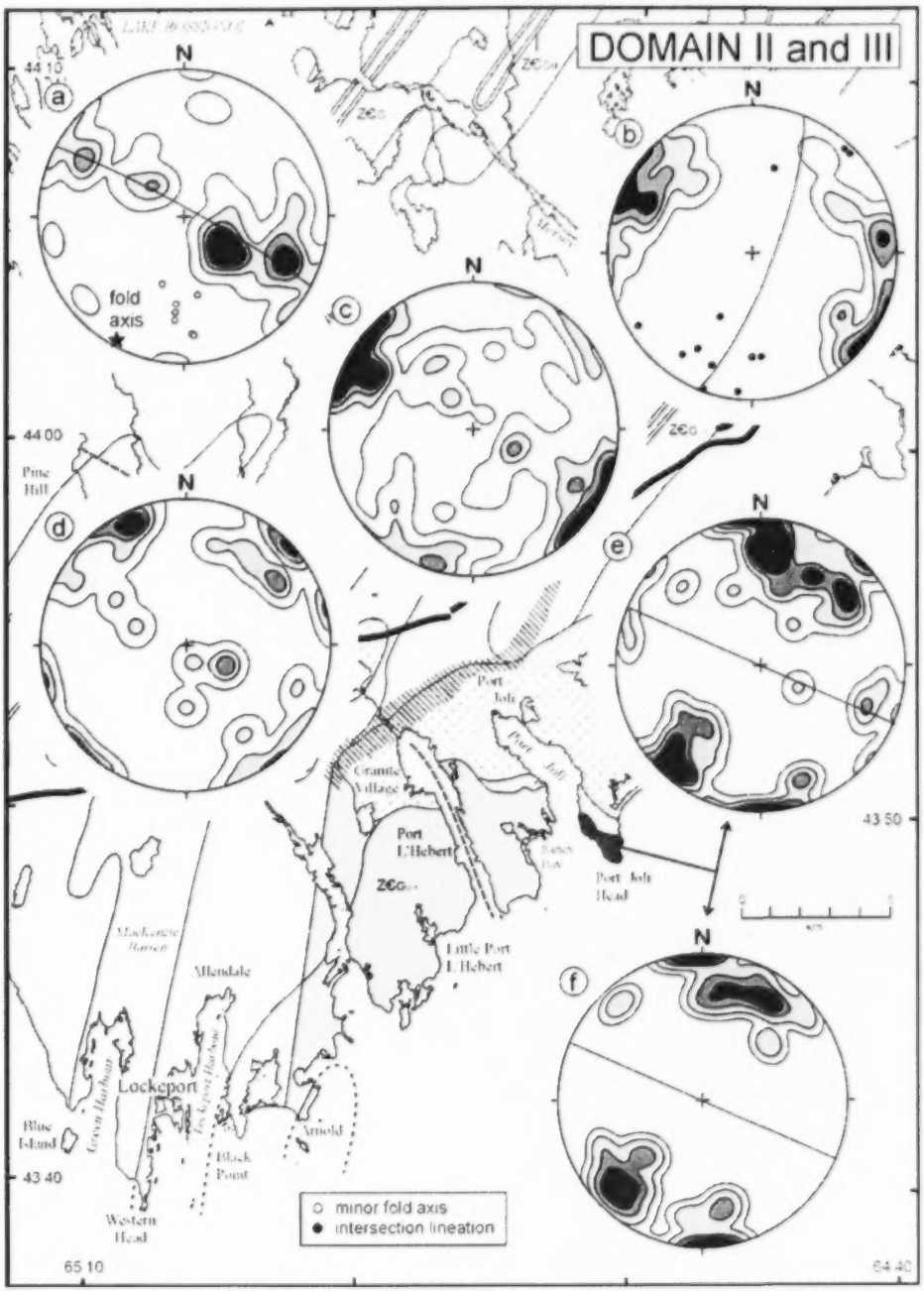


Figure 5. Equal area stereonets of structural data for Domain IV (shaded grey area) in the map area. (a) Contoured poles to bedding and minor F_1 fold axes. (b) Contoured poles to foliation and bedding-cleavage intersection lineations, solid great circle show average orientation of S_1. (c) Contoured poles to joints. (d) Contoured poles to quartz veins. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.



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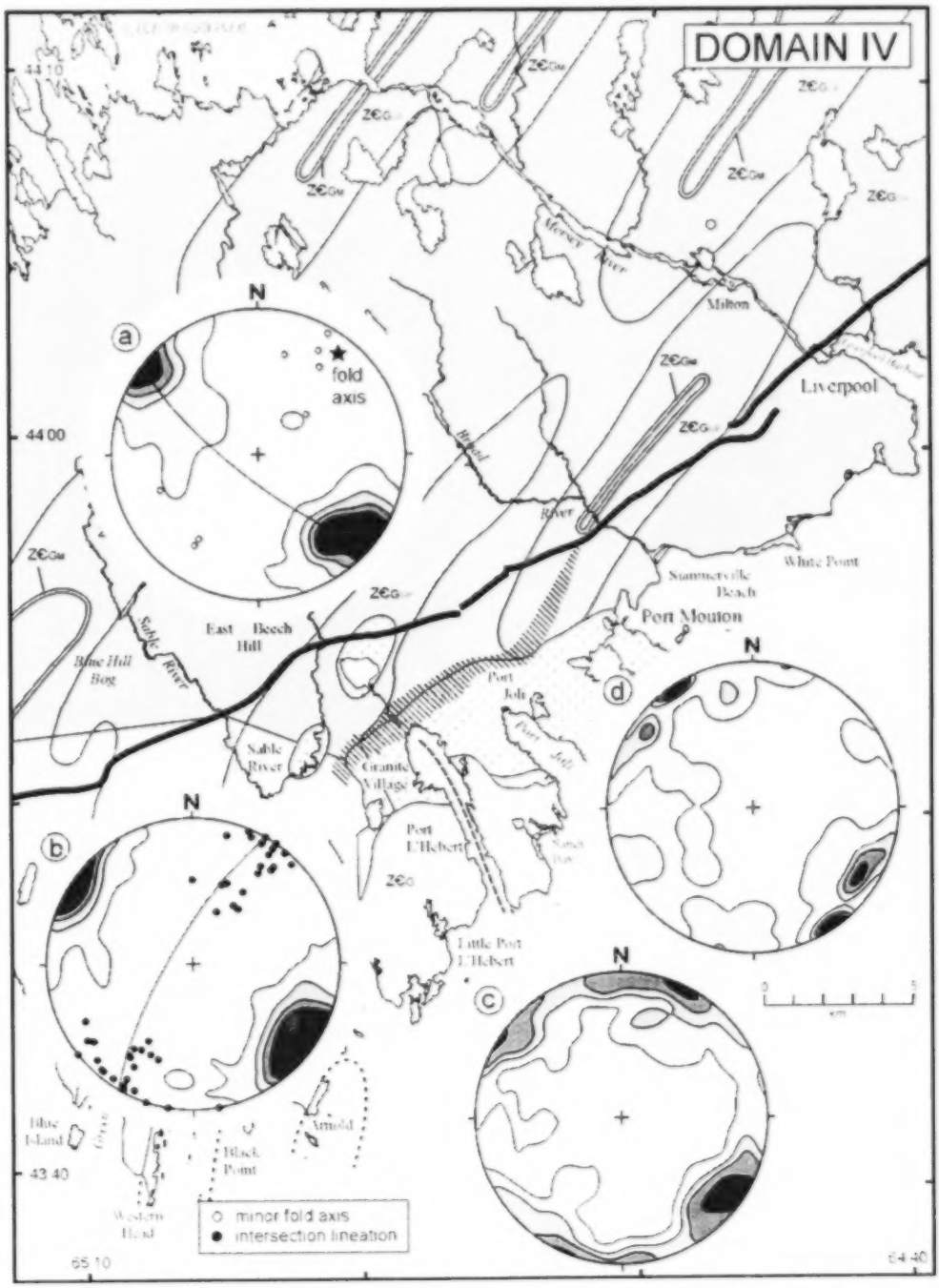

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Intersection lineations (L_1) (bedding/foliation) are somewhat scattered but generally display subhorizontal to moderate northeast-southwest plunge (Fig. 5b). Elongate calc-silicate and coticule nodules typically are parallel to the intersection lineation and minor fold axes. Contoured poles to joints display two prominent clusters. The main cluster indicates a steep, northeast-trending joint set that is parallel to the regional foliation and the second cluster indicates a steep, northwest-trending joint set that is orthogonal to the main set (Fig. 5c). Contoured poles to quartz veins also display considerable scatter, although steep, northeast-trending quartz veins parallel to those in domains I and II predominate (Fig. 5d).

Domain V comprises the main body of the Port Mouton Pluton (Fig. 6). As noted above it is locally banded and foliated. Contoured poles to banding define a well developed girdle distribution about an axis plunging moderately to the west (Fig. 6a). Because the Port Mouton Pluton is post-tectonic with respect to folding in the country rocks, it is unlikely that this girdle distribution is related to folding, but is more likely related to magmatic flow during intrusion. Contoured poles to foliation (S_1) indicate a steep northwest dipping, northeast-striking foliation (Fig. 6b), perpendicular to banding in the pluton but similar to the regional foliation orientations in domains I, II, and IV. Contoured poles to joints display considerable scatter, although the main cluster indicates a prominent steep, east-northeast-trending joint set (Fig. 6c), similar in orientation to those described by Douma (1988, 1992). Contoured poles to aplitic and pegmatitic dykes display considerable scatter, although they form two moderately well defined clusters. The main cluster indicates a north-south trend with a moderate dip to the east, whereas the other cluster indicates a steep, east-west orientation (Fig. 6d). These correspond to the orientations of pegmatite and aplite dykes, respectively (c.f. Douma, 1988, 1992). Quartz vein orientations, although scattered, display a moderately northwest-dipping, northeast-trending orientation (Fig. 6d).

Shear Zones and Faults

Several narrow (<2 m wide) shear zones have been documented in the Port Mouton Pluton (Maksaev, 1986; Douma, 1988, 1992; Currie and Whalen, 1994; Fallon *et al.*, 2001). Douma (1988, 1992) also documented a 0.5 km wide zone of 'shear fabric' in the granitic rocks along the northern margin of the pluton. New logging roads, ditch-digging, and new gravel pits and rock quarries along the northern margin of the pluton have better exposed this shear zone since the work of Douma (1988). This high-strain zone, herein termed the Granite Village shear zone, forms a wide (1 km) belt along the northern contact between the Port Mouton Pluton and the Goldenville Formation (Fig. 2). To the northeast, the shear zone thins to about a width of about 5 m and marks the boundary between the Government Point and Moshers Island members on the southeastern limb of the syncline exposed in Broad River. The contact between the Moshers Island and Cunard members is also marked by a shear zone which may be splay of the Granite Village shear zone. Due to lack of outcrop the shear zone could not be traced to the southeast. The shear zone is easily recognized in the granite and associated pegmatite by the presence of strong protomylonitic foliation and moderately developed mineral (stretching) lineation. However, recognition of the shear zone in the adjacent fine-grained metasandstone of the Goldenville Formation is not easy. Here the deformation has formed rectilinear laminations that look as if they are sedimentary in origin but upon closer inspection can be seen to contain extremely flattened, rootless isoclinal folds.

Contoured poles to the shear fabric indicate a steep, northeast-striking mylonitic foliation (Fig. 6e). This orientation is similar to the foliation in the pluton (Fig. 6b) and suggests that the two maybe related. Mineral lineations (elongate feldspar, quartz grains, and biotite patches) are steep, and minor folds in the protomylonite display shallow to moderate plunges to the southwest and northeast (Fig. 6e). In contrast, folded quartz veins in the shear zone in the Broad River area are steep and locally rootless. Kinematic indicators (asymmetric porphyroclasts and S-C fabrics) in the granite suggest southeast-side-up (granite up), dip-slip motion. Within the pluton, Currie and Whalen (1994) documented vertical and eastward movement with respect to the pluton margins. In contrast, the Granite Village shear zone exposed in Broad River displays dextral strike-slip sense of movement but more work is needed to verify this interpretation.

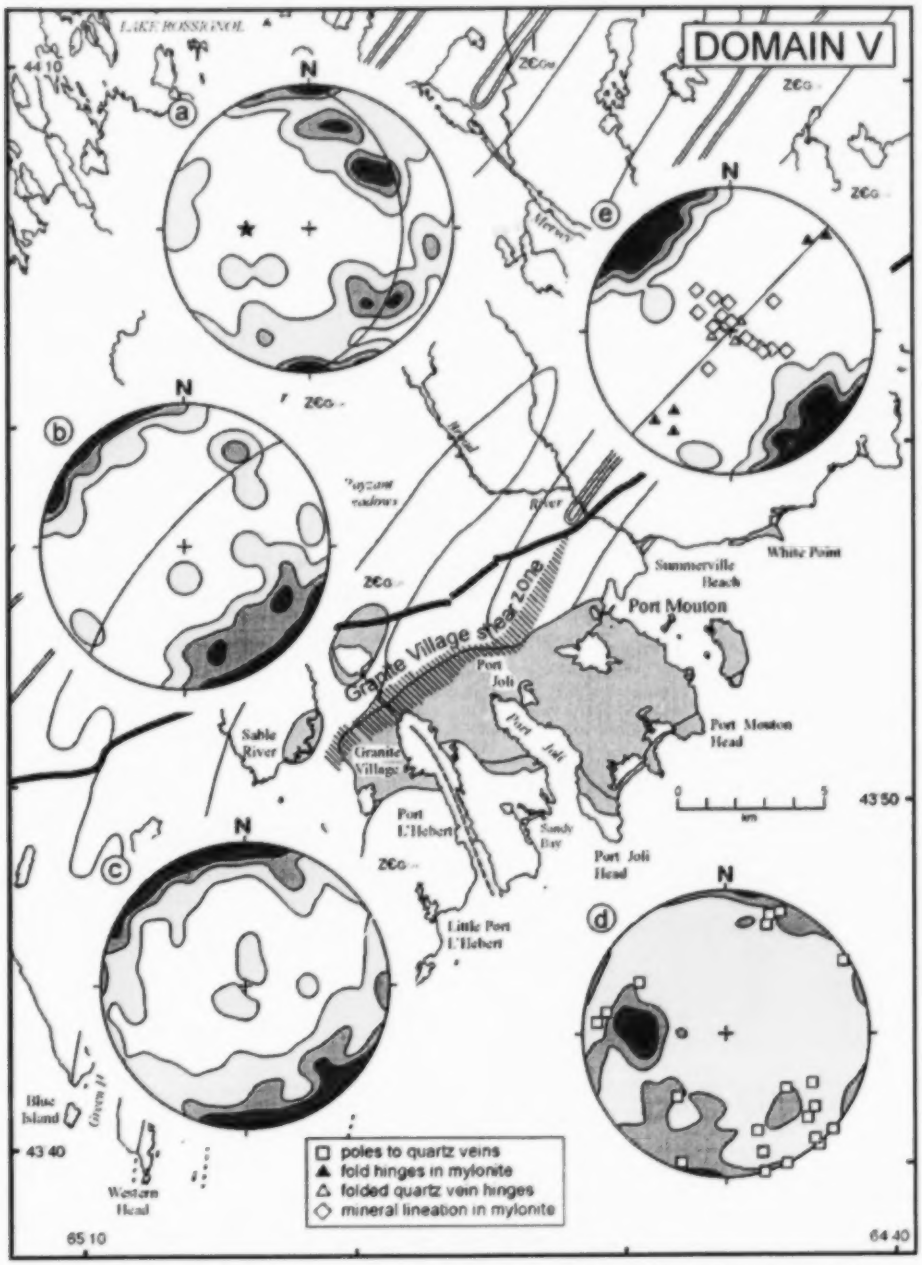

Figure 6. Equal area stereonets of structural data for Domain V (Port Mouton Pluton-shaded) in the map area. (a) Contoured poles to flow banding. (b) Contoured poles to foliation, solid great circle show average orientation. (c) Contoured poles to joints. (d) Contoured poles to pegmatite dykes, open squares are poles to quartz veins. (e) Contoured poles to mylonitic foliation, filled triangles are fold axes to minor folds, open triangles are fold axes to folded quartz veins, open diamonds are mineral lineations. Contours on stereonets at 1, 3, 5, and greater than 7% per 1% area; darkest shading indicates highest contour area.

Age of the shearing in the Port Mouton Pluton is unknown. Pegmatite dykes in the Granite Village shear zone are strongly deformed along with the host granite which suggests that deformation is younger than the pluton. However, within the pluton several pegmatitic dykes clearly cut the 'regional' foliation in the granite. If these pegmatitic dykes are similar in age to those in the north, then some mylonitization may have been synchronous with the main phase of plutonism. Currie and Whalen (1994) suggested that the deformation (mylonitization) was synchronous with emplacement and regional metamorphism and could be as young as 310-330 Ma. However, based on recent U-Pb data, the intrusive age of the pluton is well constrained at ca. 373 Ma (see Port Mouton Pluton section above). Although Fallon *et al.* (2001) suggested that the younger 315-325 Ma $^{40}Ar/^{39}Ar$ laserprobe ages from muscovite rims recorded reheating or slow cooling, it is possible that they record Alleghanian deformation that has been documented farther to the southeast (see White, 2003 for a summary).

No brittle faults were observed in outcrop in the map area. However, a northwest-trending fault is indicated by apparent offsets in aeromagnetic patterns in the Pine Hill area (Fig. 2). A brittle fault is inferred to exist in Port L'Hebert (Fig. 2) because bedding and foliation measurements on the west side of the harbour strike northeast and those on the east side strike northwest. In addition, the southern contact of the Port Mouton Pluton appears to be offset by approximately 2.5 km (Hope, 1987). Senses of movement along these faults are not known.

Pseudotachylyte veins occur at many locations throughout the area, especially in metasandstone of the Green Harbour member north of the Port Mouton Pluton. Pseudotachylyte veins have been reported in the West Dublin member (Government Point member) in the Broad River area (Hope, 1987). Many of the fractures that the veins occupy show evidence of microbrecciation along their margins and offsets up to 1-2 cm, suggesting that the veins represent *in situ* melts. In the Shelburne area farther to the southwest, similar veins have been interpreted to be associated with shallow faulting (Gareau, 1977).

Metamorphism

Based on pelitic lithologies in the Meguma Group, several metamorphic zones have been determined (Hope, 1987), similar to those defined in the map areas to the southwest (White, 1984; Bourque, 1985; Ross, 1985; Wentzell, 1985; Raeside and Jamieson, 1992). The lowest metamorphic grade rocks are in the biotite zone which is well exposed in the northeastern part of the map area (northeast of Mersey River). The biotite zone is characterized by the presence of prograde biotite, which gives the rock a spotted appearance. A typical mineral assemblage is biotite + chlorite + muscovite + quartz + plagioclase. Garnet zone rocks are similar to those in the biotite zone, except that they also contain tiny porphyroblasts of garnet and plagioclase compositions of An_{18} (Hope, 1987). This zone is well exposed in the northern and southern part of the map area. As metamorphic grade increases, cordierite appears with the same mineral assemblage as above. This area corresponds to the chlorite-cordierite zone of Hope (1987). Associated with this zone in the more aluminous rocks is rare chiastolite. Although well cleaved, rocks in the garnet and cordierite zones typically retain their original sedimentary textures but their mineral assemblage is metamorphic.

The staurolite zone is wide in the west but narrows around the Port Mouton Pluton. Most original sedimentary textures are obliterated in the pelitic lithologies. Typical mineral assemblage is staurolite + garnet + biotite + chlorite + muscovite + quartz + plagioclase. However, andalusite and cordierite are locally present and because of this, Hope (1987) termed this zone the staurolite-cordierite-andalusite zone. More work is needed to subdivide this zone. The andalusite zone (staurolite-absent zone of Hope, 1987) is marked by the disappearance of staurolite in the schist. This zone forms a wide concentric band around the Port Mouton Pluton. The typical mineral assemblage is andalusite + cordierite + garnet + biotite + muscovite + quartz + plagioclase.

The transition from the andalusite zone to the sillimanite zone is marked by the appearance of sillimanite as fibrolite. The sillimanite zone occurs adjacent to the Port Mouton Pluton up to a distance

of 500 m from the margin of the pluton (Hope, 1987). As metamorphic grade increases, andalusite and garnet decrease in abundance. Along Summerville Beach, migmatitic rocks with anatectic textures are reported (Merrett, 1987), indicating that pressures and temperatures near granitic melt conditions were reached.

Because migmatite borders part of the northern margin of the Port Mouton Pluton and the sillimanite zone is concentric around the pluton, Hope (1987) speculated that these features were related to contact metamorphism by the pluton. However, she also concluded that the regional metamorphic grade in the area was at least at andalusite grade when the pluton was emplaced. In contrast, Currie and Whalen (1994) concluded that there is no obvious contact aureole around the pluton and that the 'migmatite' showed no evidence of partial melting. However, Currie and Whalen (1994) failed to offer an alternative explanation for the apparent association of these features with the pluton and therefore the conclusion of Hope (1987) seems more plausible.

Economic Geology

Significant beryl mineralization has been documented in the map area in association with pegmatite in the Port Mouton Pluton (Oldale, 1959; Taylor, 1967; MacDonald, 1988). Beryl appears to be associated only with tourmaline-bearing pegmatite, in most places as small disseminated grains, although crystals up to 10 cm long have been reported from Port Mouton Island (Hope *et al.*, 1988). Molybdenite was also reported in pegmatite veins that cut the Goldenville Formation and Port Mouton Pluton (Hope and Woodend, 1986). Pyrite, chalcopyrite, and magnetite occur along narrow zones parallel to schistosity in a biotite-muscovite schist along the east side of Jordan Bay (Hope and Woodend, 1986). Skarnoid calc-silicate nodules close to the pluton may contain pyrrhotite, chalcopyrite, and scheelite similar to those in the Digby area (Horne *et al.*, 2000) and the Barrington area (Mitchell, 2004). The only gold occurrence in the area was reported in quartz veins along Broad River by Faribault (1915). This occurrence was not confirmed during the present study.

From an industrial minerals perspective, the map area holds great potential. The local community is making use of sand and gravel to produce cement and asphalt. The Port Mouton Pluton has been quarried for aggregate in the making of Highway 103 and rip-rap used in building breakwaters.

Summary

A major result of the mapping during the summer of 2004 is the confirmation that stratigraphy in the Goldenville and Halifax formations is identical to that defined in the map area to the southwest (e.g. White and Wasylik, 2003) and farther northeast in Lunenburg counties (O'Brien, 1986, 1988; Waldron, 1992). In addition, the Moshers Island member is recognized as part of the upper-most Government Point member of the Goldenville Formation and not the lower Halifax Formation.

Regional folds trend north-south in the southern part of the map area with near horizontal fold axes, whereas folds in the northern part trend northeast with gentle southwest- and northeast-plunging fold axes. Folds in both areas have well developed axial planar cleavage. In the area south of the Port Mouton Pluton, bedding and foliation trend northeast, orthogonal to the regional fabric.

Peak amphibolite-facies regional metamorphism appears to have coincided with emplacement of the Port Mouton Pluton at ca. 373 Ma. If so, it is considerably younger than the ca. 400 Ma greenschist-facies regional metamorphism in the Meguma Group elsewhere in the Meguma terrane.

A major shear zone (Granite Village shear zone) marks the northern boundary of the Port Mouton Pluton and had steep, dip-slip movement with the granite up relative to the country rocks. The regional extent and age of this shear zone in unknown but based on muscovite rim ages, it may have been related to the Carboniferous Alleghanian Orogeny.

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References

Bailey, L. W. 1896: Report on the geology of southwest Nova Scotia embracing the counties of Queens, Shelburne, Yarmouth, Digby and parts of Annapolis; Geological Survey of Canada, Annual Report, New Series, v. 19, part M, p. 1-154.

Bourque, A. D.1985: Migmatization and metamorphism associated with the Barrington Passage Pluton, Shelburne and Yarmouth counties, Nova Scotia; unpublished BSc Honours thesis, Acadia University, Wolfville, Nova Scotia.

Clarke, D. B., Fallon, R. and Heaman, L. M. 2000: Interaction among upper crustal, lower crustal, and mantle materials in the Port Mouton pluton, Meguma Lithotectonic Zone, southwest Nova Scotia; Canadian Journal of Earth Sciences, v. 37, p. 579-600.

Currie, K. L. and Whalen, J. B. 1994: A note on the occurrence of beryl in the Port Mouton pluton, southwestern Nova Scotia; *in* Current Research 1994-D, Geological Survey of Canada, p. 73-77.

Currie, K. L., Whalen, J. B., Davis, W. J., Longstaffe, F. J. and Cousens, B. L. 1998: Geochemical evolution of peraluminous plutons in southern Nova Scotia, Canada-a pegmatite-poor suite; Lithos, v. 44, p. 117-140.

Douma, S. L. 1988: The mineralogy, petrology, and geochemistry of the Port Mouton Pluton, Nova Scotia, Canada; unpublished M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Douma, S. L. 1992: Field relationships, mineralogy and structural features of the Port Mouton Pluton, southwestern Nova Scotia; Atlantic Geology, v. 28, p. 85-100.

Faribault, E. R. 1914: Greenfield and Liverpool Town map-areas, Nova Scotia; Geological Survey of Canada, Summary Report 1912, p. 372-382.

Faribault, E. R. 1915: Geology of the Port Mouton map-area, Queens County, Nova Scotia; Geological Survey of Canada, Summary Report 1913, p. 251-258.

Faribault, E. R. 1918: Investigations in western Nova Scotia; Geological Survey of Canada, Summary Report 1917, Part F, p. 17-20.

Faribault, E. R. 1920: Investigations in western Nova Scotia; Geological Survey of Canada, Summary Report 1919, Part F, p. 2-20.

Fallon, R. P., Reynolds, P. H. and Clarke, D. B. 2001: A comparative $^{40}Ar/^{39}Ar$ conventional and laserprobe study of muscovite from the Port Mouton pluton, southwest Nova Scotia; Canadian Journal of Earth Sciences, v. 38, p. 347-357.

Gareau, M. B. 1977: Pseudotachylytes of southwestern Nova Scotia; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Hicks, R. J., Jamieson, R. A. and Reynolds, P. H. 1999: Detrital and metamorphic $^{40}Ar/^{39}Ar$ ages from muscovite and whole-rock samples, Meguma Supergroup, southern Nova Scotia; Canadian Journal of Earth Sciences, v. 36, p. 23-32.

Hope, T. L. 1987: Geology and metamorphism in the Port Mouton-Lockport area, Queens and Shelburne counties, Nova Scotia; unpublished M.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Hope, T. L. and Woodend, S. L. 1986: Geological mapping and igneous and metamorphic petrology, Queens and Shelburne counties, Nova Scotia; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 429-433.

Hope, T. L., Douma, S. L. and Raeside, R. P. 1988: Geology of the Port Mouton-Lockport area, southwestern Nova Scotia; Geological Survey of Canada, Open File 1768.

Horne, R. J., White, C. E., Muir, C., Young, M. D. and King, M. S. 2000: Geology of the Weymouth-Church Point area (NTS 21A/05 and 21B/08, southwest Nova Scotia; *in* Report

of Activities 1999, eds. D. R. MacDonald and K. A. Mills; Nova Scotia Department of Natural Resources, Mines and Energy Branch Report ME 2000-1, p. 75-91.

Keppie, J. D. 1985: The Appalachian collage; *in* The Caledonide Orogen: Scandanavia and related areas; eds. D. G. Gee and B. A. Sturt; John Wiley, New York, p. 1217-1226.

Keppie, J. D. and Dallmeyer, R. D. 1995: Late Paleozoic collision, delamination, short-lived magmatisim, and rapid denudation in the Meguma Terrane (Nova Scotia, Canada): constraints from $^{40}Ar/^{39}Ar$ isotopic data; Canadian Journal of Earth Sciences, v. 32, p. 644-659.

King, M. S. 1997a: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 21A/02, Liverpool, Queens and Lunenburg counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-023.

King, M. S. 1997b: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 21A/03, Lake Rossignol, Shelburne, Yarmouth, Queens and Digby counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-024.

King, M. S. 1997c: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 20P/14, Shelburne, Shelburne and Queens counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-032.

King, M. S. 1997d: Meguma Terrane, enhanced (second vertical derivative) aeromagnetic digital data for NTS 20P/15, Port Mouton, Queens and Shelburne counties, Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Open File Map 97-033.

MacDonald, D. 1988: Examination of a zoned pegmatite and host rocks at Port Joli, Nova Scotia; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Maksaev, V. 1986: The origin of banding in the Mountain Island Granite, southern Nova Scotia; unpublished Internal Report, Dalhousie University, Halifax, Nova Scotia.

Merrett, D. 1987: The migmatites of Port Mouton; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Mitchell, F. 2004; Metamorphic petrology of calc-silicate nodules from greenschist facies to migmatite grade, Liverpool-Pubnico area, Nova Scotia; unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

Muecke, G. K, Elias, P. and Reynolds, P. H. 1988: Hercynian/Alleghanian overprinting of an Acadian Terrane: $^{40}Ar/^{39}Ar$ studies in the Meguma Zone, Nova Scotia; Chemical Geology, v. 73, p. 153-167.

Muir, C. M. 2000: An $^{40}Ar/^{39}Ar$ study of the Goldenville, Halifax, White Rock and Torbrook formations of the Digby area, southwest Nova Scotia; unpublished B.Sc. thesis, Dalhousie University, Halifax, Nova Scotia.

Murphy, J. B., Van Staal, C. R. and Keppie, J. D. 1999: Middle to Late Paleozoic Acadian orogeny in the northern Appalachians: a Laramide-style plume-modified orogeny?; Geology, v. 27, p. 653-656.

O'Brien, B. H. 1986: Preliminary report on the geology of the Mahone Bay area, Nova Scotia; *in* Current Research, Part A, Geological Survey of Canada, Paper 86-1A, p. 439-444.

O'Brien, B. H. 1988: A study of the Meguma Terrane in Lunenburg County, Nova Scotia; Geological Survey of Canada, Open File 1823.

Oldale, H. R. 1959: Beryllium, Port Mouton, Queens County, Nova Scotia; Preliminary Report, Nova Scotia Department of Mines, 20P/15C 08-N-18(01).

Raeside, R. P. and Jamieson, R. A. 1992: Low-pressure metamorphism of the Meguma Terrane, Nova Scotia; Geological Association of Canada/Mineralogical Association of Canada Joint Annual Meeting, June 1992; Field Excursion C-5: Guidebook.

Reynolds, P. H., Elias, P., Muecke, G. K. and Grist, A. M. 1987: Thermal history of the southwestern Meguma Group, Nova Scotia, from $^{40}Ar/^{39}Ar$ and fission track dating study of intrusive rocks; Canadian Journal of Earth Sciences, v. 24, p. 1952-1965.

Ross, D. M. 1985: Structure and metamorphism of the Pubnico area, Yarmouth County, Nova Scotia; unpublished BSc Honours thesis, Acadia University, Wolfville, Nova Scotia.

Tate, M. C. and Clarke, D. B. 1995: Petrogenesis and regional tectonic significance of Late Devonian mafic intrusions in the Meguma Zone, Nova Scotia, Canada; Canadian Journal of Earth Sciences, v. 32, p. 1883-1898.

Taylor, F. C. 1967: Reconnaissance Geology of Shelburne map-area, Queens, Shelburne, and Yarmouth Counties, Nova Scotia; Geological Survey of Canada Memoir 349.

Waldron, J. W. 1992: The Goldenville-Halifax transition, Mahone Bay, Nova Scotia: relative sea-level rise in the Meguma source terrane; Canadian Journal of Earth Sciences, v. 29, p. 1091-1105.

Wentzell, B. D. 1985: The transition from staurolite to sillimanite zone, Port LaTour, Nova Scotia; unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

White, C. E. 1984: Structure and metamorphism of the Jordan River valley, Shelburne County, Nova Scotia; unpublished B.Sc. thesis, Acadia University, Wolfville, Nova Scotia.

White, C. E. and Barr, S. M. 2004: Age and petrochemistry of mafic sills in rocks of the northwestern margin of the Meguma Terrane, Bear River-Yarmouth area of southwestern Nova Scotia; *in* Minerals and Energy Branch, Report of Activities 2003; Nova Scotia Department of Natural Resources, Report 2004-1, p. 97-117.

White, C. E. and King, 2002: Preliminary bedrock geology of the Tusket map area (NTS 20P/13), southwestern Nova Scotia; *in* Minerals and Energy Branch, report of activities 2001; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Report ME 2002-1, p. 141-158.

White, C. E. and Wasylik, D. R. G. 2003: Preliminary bedrock geology map of the area between Baccaro Point and Sable River, Shelburne County (NTS 20P/06, 11, and 14); *in* Mining Matters for Nova Scotia 2003, Nova Scotia Department of Natural Resources, Minerals Resources Branch, Report ME 2003-2, p. 20.

White, C. E., Horne, R. J., Muir, C. and Hunter, J. 1999: Preliminary bedrock geology of the Digby map sheet, southwestern Nova Scotia; *in* Minerals and Energy Branch, report of activities 1998; Nova Scotia Department of Natural Resources, Mines and Energy Branch, Report 98-1, p. 119-134.

White, C. E., Horne, R. J., Tèniére, P. J., Jodrey, M. J. and King, M. S. 2001: Geology of the Meteghan River-Yarmouth area: a progress report on the Southwest Nova Scotia Mapping Project; i*n* Minerals and Energy Branch, Report of Activities 2000, Nova Scotia Department of Natural Resources, Mines and Energy Branch, Report 2000-1, p. 95-111.

White, C. E. and Barr, S. M. 2004: Age and petrochemistry of mafic sills of the northwestern margin of the Meguma terrane in the Bear River - Yarmouth area of southwestern Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2003; ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report 2004-1, p. 7-117.

White, C. E. 2003: Preliminary bedrock geology of the area between Chebogue Point, Yarmouth County, and Cape Sable Island, Shelburne County, southwestern Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2002; ed. D. R. MacDonald; Nova Scotia Department of Natural Resources, Report 2003-1, p. 127-145.

White, C. E., Barr, S. M. and Gould, R. C. 2003: Gabbroic intrusions in the Meteghan-Yarmouth area (NTS 21A/04, 21E/01, 20P/13 and 20O/16) of the Meguma Terrane, southern Nova Scotia; *in* Mineral Resources Branch, Report of Activities 2002; ed. D. R. MacDonald;. Nova Scotia Department of Natural Resources, Report 2003-1, p. 147-162.

On the Discovery of Tetrapod Trackways from Permo-Carboniferous Redbeds of Prince Edward Island and their Biostratigraphic Significance[1]

J. H. Calder, D. Baird[2] and E. B. Urdang[3]

The first fossil tetrapod footprints that were discovered on Prince Edward Island, and which were previously undescribed, are small reptilian trackways assignable to the ichnogenera *Notalacerta* and *Gilmoreichnus*. Their closest zoological correlatives are small, Permo-Carboniferous "stem-reptiles" of the families Protorothyrididae and Captorhinidae in the suborder Captorhinomorpha, and pelycosauran reptiles, possibly of the Ophiacodontidae. Reptiles of this type are rare to unrepresented in the skeletal fauna of the province. The biochronology of the track-bearing bed, combined with terrestrial vertebrate, palynological and macrofloral records, suggest that the host Pictou Group redbeds on Prince Edward Island young from late Stephanian (Pennsylvanian) at Malpeque Bay to early Permian in the north. The combined discoveries of tetrapod footprints and trackways from these Permo-Carboniferous redbeds suggests that the record is potentially extensive. Now included in this record is the youngest known occurrence of the ichnogenus *Notalacerta*.

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UNESCO World Heritage and the Joggins Cliffs of Nova Scotia[1]

H. J. Falcon-Lang[2] and J. H. Calder

UNESCO World heritage status is the highest honour that may be bestowed on a palaeontological site. In addition to heightening conservation status, it confers international recognition of a locality's 'outstanding universal value' and often triggers the release of substantial regional development funds. Despite these incentives it is, perhaps, not surprising that only a handful of fossil sites have successfully navigated the World Heritage selection process. In this feature, we draw on our recent experience of developing a World heritage bid for the Pennsylvanian 'Coal Age' locality of Joggins, Nova Scotia. As well as demonstrating the huge significance of Joggins, we hope that our findings will provide valuable guidelines for the assessment of World Heritage fossil sites in general.

[1]*In* Geology Today, 2004, v. 20 (4), p. 140-144
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An Early Pennsylvanian Waterhole Deposit and its Fossil Biota in a Dryland Alluvial Plain Setting, Joggins, Nova Scotia[1]

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The terrestrial ecology of Pennsylvanian tropical wetlands is understood in detail, but coeval dryland ecosystems remain highly enigmatic. To fill this gap in our knowledge, a Pennsylvanian (Langsettian) continental red-bed succession was studied at the classic Joggins locality, Nova Scotia. These units represent the deposits of seasonally dry, alluvial plains traversed by anastomosed drainage networks. One channel complex informally known as the 'Hebert beds' (the focus of this study) contains an unusual fossil assemblage and is interpreted as an alluvial waterhole deposit that formed following drought-induced cessation of channel flow. Adpressed and charred fossil plant remains indicate that the alluvial plain surrounding the waterhole was covered by fire-prone cordaite vegetation, with hydrophylic lycopsids and sphenopsids restricted to waterlogged riparian niches. Gigantic unionoid freshwater bivalves, locally in life position, and occurring in large numbers in the waterhole, were probably infaunal suspension feeders during periods of fluvial activity, but aestivated in channel bottom muds when flow ceased. Abundant terrestrial gastropods found clustered around fossil plant detritus mat have been deposit feeders scavenging dry portions of channel floors. Common partially articulated remains of small to medium-sized tetrapods possibly represent animals drawn to the waterhole during drought when surface water was scarce elsewhere. In terms of both sedimentology and biology, the Hebert beds alluvial complex bears a very close similarity to the seasonal drainages and waterholes of present-day central and northern Australia. This unique deposit sheds significant light on the nature of Pennsylvanian dryland tropical ecology.

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On the Discovery of a Unique Terrestrial Faunal Assemblage in the Classic Pennsylvanian Section at Joggins, Nova Scotia[1]

B. L. Hebert[2] and J. H. Calder

A rich fossil assemblage discovered from the classic Pennsylvanian locality of Joggins, Nova Scotia, is here described for the first time. The two metre thick Hebert sandstone, within the lower Joggins Formation of early Langsettian age, is the most productive stratum at Joggins of terrestrial tetrapods and the pulmonate gastropod *Dendropupa vetusta* exclusive of the historic fossil forest locality of Dawson and Lyell, and the most productive Pennsylvanian locality in the world of the large unionoid bivalve genus *Archanodon*. Although the land snail-archanodontid bivalve-tetrapod assemblage of the Hebert Sandstone comprises a unique Late Paleozoic terrestrial dryland biota, individual taxa were not endemic to drylands alone.

[1]*In* Canadian Journal of Earth Sciences, 2004, v. 41, p. 247-254
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Tetrapod Footprints from Nova Scotia: The Rosetta Stone for Carboniferous Tetrapod Ichnology[1]

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The fossil record of tetrapod footprints from Nova Scotia is the most stratigraphically complete record known for the Carboniferous. Discovered in 1841, it encompasses three well sampled intervals and least two more less studied horizons and is directly overlain by a large assemblage of earliest Permian tracks. The oldest footprint assemblage, from the Tournaisian Horton Bluff Formation, is the oldest known tetrapod ichnofauna and documents a pentadactyl tetrapod fauna capable of fully terrestrial locomotion early in the Mississippian. It thus indicates a major turnover in tetrapod evolution at approximately the Devonian-Mississippian boundary, with the replacement of the ichtyostegalian chronofauna by the reptiliomorph/anthracosaur chronofauna. The late Viséan-Namurian West Bay Formation yields an ichnofauna dominated by anthracosaur, captorhinomorph and temnospondyl tracks and thus well represents the classic mid-Carboniferous (Viséan-Namurian) tetrapod chronofauna known from body fossils. The early Westphalian Joggins locality is the most diverse Carboniferous ichnofauna in Nova Scotia and was the focus of early historic studies. It includes numerous temnospondyl tracks (*Batrachichnus*), at least three types of captorhinomorph tracks (*Notolacerta*, *Pseudobradypus*, "*Hylopus*") and numerous anthracosaur/reptiliomorph ("*Baropezia*") tracks. The age equivalent (Westphalian A) Parrsboro Formation yields the same ichnofauna, as do less well sampled, younger Westphalian sites (Abercrombie, Wallace River). Footprints from the Westphalian-Stephanian boundary in the Sydney Basin document the lowest occurrences of *Dimetropus* and *Limnopus*, and thus signal the appearance of the edaphosaurid chronofauna. Earliest Permian footprints from Brule document a classic red-bed ichnofauna well known from the Wolfcampian of the American Southwest and the upper part of the European Rotliegendes. The Brule ichnofauna includes *Batrachichnus*, *Limnopus*, *Amphisauropus*, *Varanopus*, *Dromopus* and *Dimetropus*. The Nova Scotian track record thus documents major junctures in tetrapod evolution at the bases of the Mississippian, Westphalian and Stephanian and both adds to and reinforces the body fossil record of Carboniferous tetrapod evolution.

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The Oldest Tetrapod Footprint Ichnofauna, from the Lower Mississippian Horton Bluff Formation, Nova Scotia, Canada[1]

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At Blue Beach, Nova Scotia, Canada, the Blue Beach and Hurd Creek members of the lower Mississippian (Tournaisian) Horton Bluff Formation yield an extensive assemblage of tetrapod footprints that is the oldest known fully terrestrial (exclusive of ichthyostegalians) tetrapod ichnofauna. Four ichnotaxa were previously reported from Blue Beach (*Baropezia*, *Hylopus*, *Palaeosauropus* and *Anticheiropus*) but new, extensive collections indicate that six footprint morphotypes are present: (1) abundant tracks ("*Paleosauropus*") that are wider than long (pes width/length ~ 50-70/30-40 mm), with clear manus and pes sole impressions, and tetradactyl manus and pentadactyl pes with relatively short, clawed digits; (2) common tracks ("*Hylopus*") that have long, thin and sometimes curved digits (pes width/length ~ 40/40 mm) in which relative digit length is well differentiated; (3) common tracks ("*Pseudobradypus*") that have a long, narrow pes (pes width/length ~ 30/50 mm) and thin, pointed and forward-directed digits and a narrow trackway width, some with a median drag; (4) several very large (pes width/length ~ 80/70 mm) tracks ("*Attenosaurus*"), which have long, thin scratch-like digit impressions; (5) rare, large (pes width/length ~ 120/100 mm) tracks ("*Baropezia*") in which a large pes sole impression and five short, rounded digits are evident; and (6) rare, small (pes < 20 mm long) tracks with short, blunt digits ("*Batrachichnus*"). These tracks are consistent with reptiliomorphs (1), captorhinomorphs (2-3), anthracosaurs (4-5) and temnospondyls (6). None of the Horton Bluff tracks show evidence of polydactyly, and thus they are not those of ichthyostegalians. They indicate that a major revolution had taken place in tetrapod evolution at approximately the Devonian-Mississippian boundary, with the replacement of the ichthyostegalian chronofauna of the Late Devonian by the reptiliomorph/anthracosaur chronofauna of the Mississippian. Almost all the Horton Bluff footprints are subaerial tracks of quadrupeds that have forward directed digits and lack median body or tail drags. They thus indicate a pentadactyl tetrapod fauna capable of fully terrestrial locomotion early in the Mississippian.

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Vegetation-induced Sedimentary Structures from Fossil Forests in the Pennsylvanian Joggins Formation, Nova Scotia[1]

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Vegetation-induced sedimentary structures (VISS) are primary structures formed by the interaction of detrital sediment with *in situ* plants. VISS provide physical evidence of vegetation's fundamental role in mediating sediment accumulation and erosion in clastic depositional systems. Despite the abundance of modern VISS, descriptions from the ancient record are surprisingly rare. Analysis of fossil forests in floodplain strata of the Pennsylvanian Joggins Formation has identified seven types of VISS. Five hydrodynamic types comprise simple forms developed around a single plant (centroclinal cross-strata, scratch circles, upturned beds) and complex forms where structures have amalgamated between several plants (coalesced scour fills, scour-and-mound beds). Two types (mudstone-filled hollows, downturned beds) form by the decay of an entombed plant and represent infilling of an empty hollow and/or soft-sediment deformation. Hydrodynamic types are present in both dryland and wetland settings, whereas decay-related types occur only in dryland settings where the water table was perennially or periodically low. VISS represent significant accumulations of sediment and are present in a high proportion of Joggins Formation strata. The paucity of descriptions from the ancient record suggests that these structures have been overlooked or misrepresented as strictly hydrodynamic. Recognition of VISS in early to middle Palaeozoic strata may provide an important insight into the distribution of early land plants in oxidizing environments where organic material was not preserved.

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